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Establishing bona fide physiological employment standards for firefighters

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<u>**ESTABLISHING *BONA FIDE* PHYSIOLOGICAL EMPLOYMENT STANDARDS FOR FIREFIGHTERS**</u>

A thesis submitted in partial fulfilment of the

requirements for the award of the degree

Master of Science (Research)

from

University Of Wollongong

by

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DECLARATION

I, Hugh Head Kelsham Fullagar, declare that this thesis, is submitted in partial fulfilment of the requirements for the award of Masters of Science (Research) in the School of Health Sciences, University of Wollongong, and is wholly my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualifications at any other academic institution.

Hugh Head Kelsham Fullagar

Date: 24th April 2013

ABSTRACT

Extensive research has shown that during emergency and rescue operations, heavy physical demands are placed upon firefighters. Employees within this field are expected to possess the necessary physical and physiological attributes to tolerate the physical demands of the occupation. Thus, it is crucial to identify firefighters who are well suited to cope with these demands. This will aim to increase the capability, whilst minimising the risk of injury, of the fire-fighting workforce. There have been numerous changes to operational requirements and equipment (Fire & Rescue NSW News, 2011) since the work done from which the current entry-level physical screening tests for New South Wales recruit firefighters are based (Gledhill and Jamnik, 1992a and 1992b). Given these changes, it has become necessary to re-evaluate the physical and physiological demands of contemporary fire fighting, as performed within Australia. Therefore, this project sought to develop *bona fide* (legally defensible) physiological employment standards for firefighters. Three separate investigations were conducted. The first involved a comprehensive evaluation of the demands of fire fighting to identify the most essential and physically demanding trade tasks performed by firefighters. Through an employee survey and inclusion and exclusion criteria, a list of fifteen trade tasks were established and recommended for detailed study. In the second investigation, the physical and physiological demands of these tasks were evaluated and quantified. This determined the physical and physiological attributes necessary to perform fire-fighting duties in an optimal and safe manner. Thus, a preliminary set of eleven criterion screening items were established from which a legally defensible physiological screening test could be established. Therefore, in the third investigation, a legally defensible physiological screening test for firefighters was developed. Following the development of this test, recommendations were also put forward to investigate and validate, where applicable, alternative approaches to the mere duplication or simulation of critical fire-fighting tasks which may predict fire-fighting performance. Taken collectively, these findings suggest individuals who successfully pass the developed screening test will possess the physical and physiological attributes necessary to cope with the physical and physiological demands of contemporary fire fighting, as performed within NSW, Australia.

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

1.1.1 Conceptual introduction

Numerous occupations around the world place high, and sometimes excessive, physical demands on the body. Indeed, fire fighting is recognised globally as an extremely physically demanding occupation, requiring various physical attributes, such as muscular strength, and physiological attributes, such as high aerobic fitness (Davis *et al.*, 1982; Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001a; Barr *et al.,* 2010), to tolerate the demands of this profession. It is additionally crucial that firefighters possess the necessary medical profile, to ensure the employee does not exhibit conditions which may cause potential acute health incapacities. Capable firefighters are most likely to undertake the essential and physically demanding fire-fighting tasks in a safe and productive manner, and the focus of this project is upon evaluating these demands and determining the physical and physiological attributes suited for this form of employment.

Firefighters are required to perform tasks of varying intensities, under stressful environmental conditions and for unpredictable durations (Budd, 2001). These tasks aim to preserve both life and property. For example, firefighters may be required to carry heavy equipment up several flights of stairs, use power tools to enter buildings and to safely drag and operate a fully charged hose, all while wearing full personal protective equipment (PPE) and a self-contained breathing apparatus (SCBA). Indeed, ranges of joint motion, balance and physical endurance are reduced by 20-30% due to the personal protective equipment used within Fire & Rescue NSW (Taylor *et al.*, 2010a). Unstable structures and extreme environmental temperatures are further issues a firefighter encounters during a typical fire suppression operation. Therefore, it is not sufficient to consider just the task itself, but also the circumstances under which such tasks are performed.

Physiological employment standards are a set of requirements that each employee must demonstrate the capacity to meet, to ensure they are able to perform within the occupation in a safe and efficient manner (Gledhill and Bonneau, 2001; Gledhill *et al.,* 2001). These standards are developed to increase worker capability and consequentially decrease injury rates. Numerous organisations involved in occupations with heightened physical demands will screen potential employees to maximise the recruitment process and identify those best suited to deal with these demands. To increase worker capability, it is essential to have a valid pre-employment screening test in place, since an invalid screening test can reject capable individuals (false negatives) and accept incapable individuals (false positives). Thus, the employer must ensure correct procedures are in place for identifying both types of people. These procedures must be legally defensible (Gledhill and Bonneau, 2001; Gledhill *et al.,* 2001).

Indeed, physiological employment standards are subject to ongoing legal jurisdiction. In Australia, the standards of any organisation must firstly comply with occupational health and safety legislation (New South Wales Government, 2000). Employers are obligated to show a duty of care, to ensure that the demands of work do not place unacceptable hazzards on the employee. Thus, it is crucial to identify those individuals who are less capable of performing job tasks in a safe manner in the workplace and therefore exposed to an unacceptable risk of injury.

Notwithstanding these obligations, Fire & Rescue NSW currently has an annual injury rate of 17.1%. This means that 169.4 years of working time is lost each year (Taylor and Kerry, 2010). Since 1998, injuries have increased 41%, with a greater proportion of injuries occurring in older males, specifically those in the 40-50 and 50-60 year old groups. Indeed, it has been established that Fire & Rescue NSW would save on average $5,687,934 per annum if the injury rates in firefighters >40 years old could match those seen in 30-40-year-old firefighters (Taylor and Kerry, 2010). Given the demands of fire-fighting do not change regardless of age or gender (Lusa *et al.,* 1994), then a need exists for both a reduction in injury risk and an increase in worker capability. This may possibly be achieved through the development of *bona fide* age- and gender-neutral physiological employment standards (Gledhill and Bonneau, 2001; Gledhill *et al.,* 2001). Herein lies the purpose of the current project.

Current entry level physical screening tests for NSW recruit firefighters are based on well established, but now quite old research (Gledhill and Jamnik, 1992a and 1992b). This research was conducted on Canadian firefighters and based upon Canadian fire-fighting practise. Since this work, operational requirements and equipment have changed, including alternative structural fire-fighting procedures and new appliance implementations (Fire & Rescue NSW News, 2011). Given these changes, the time has come to re-evaluate the physical and physiological demands of contemporary fire fighting, as performed within New South Wales.

Finally, organisations have obligations to maintain equal employment opportunities. When physical employment standards are established, tests are used to predict those who can safely perform the required task demands within a trade. In accordance with the Anti-Discrimination Act (1977), Australian employers must ensure equal treatment for all potential candidates during the recruiting process, regardless of age, gender or race. If discriminatory practise is conducted upon one sub-group of the population, an adverse impact is deemed to have taken place (Fair Work Act, 2009). For example, the case of Meiorin (Supreme Court of Canada, 1999) led to the establishment of a threshold for such adverse impact cases. If less than 80% of applicants from a sub-group sector pass an established pre-employment standard then the standard may exert an adverse impact upon that group of individuals (Equal Employment Opportunity Commission, 1978; Gledhill *et al.*, 2001). Therefore, if the organisation cannot demonstrate that the potential employee places an excessive burden (undue hardship) or present a safety risk on the employer, then it must explore all avenues to accommodate job applicants (Hatfield, 2005).

1.1.2 Worker capability and minimising injury risk

The diminishing effect of advancing age on the ability to deal with physically demanding occupations (Saupe *et al.,* 1991, Sothmann *et al.,* 1992a) can result in increases in injury risk and will place an immense financial burden on the employer (Walton *et al.*, 2003; Taylor and Kerry, 2010). However, Taylor and Kerry (2010) report that the skewed injury data distribution towards older males is principally due to the firefighters' sedentary lifestyle habits rather than their ageing *per se*. Given the findings of this work, and that males account for more than 90% of the workforce (NSW Fire Brigades, 2010), this has significant recruitment implications for Fire & Rescue NSW. These injury data indicate firefighters have failed to maintain an adequate standard of fitness relative to the occupation. Consequentially, there is an increased likelihood of these firefighters getting injured on the job (Taylor and Kerry, 2010).

Provinces throughout the United States experienced an estimated average of 40,270 firefighter fire ground injuries *per annum* and injury rate of almost 12% for the period 2003-2006 (Karter, 2009). Furthermore, injury classification (muscle sprains and strains) and injury sites (back and knee) per 1000 firefighters are similar internationally (Lillicrap and Marriott, 1991; Coward, 2004; Albert, 2009; Karter, 2009; Taylor and Kerry, 2010). The extreme physical demands of emergency rescue operations (Sothmann *et al.,* 1992b; Taylor *et al.*, 2010b), heavy manual lifting (Walton *et al.,* 2003) and the effect of prolonged shift work on postural stability (Sobeih *et al.*, 2006), all of which are common fire-fighting practise (personal communication, Fire & Rescue NSW), would presumably play some role in this high prevalence of injuries in firefighters. Another, and perhaps more likely, possibility is that firefighters do not possess the physical and physiological attributes necessary to tolerate the demands of contemporary fire fighting. This will predispose the individual to an increased injury hazard. The employer is thus obligated to facilitate recruitment and correctly identify individuals capable of performing the job, through valid screening tests that represent the trade-specific duties of contemporary firefighters.

The decline in the fitness of firefighters after recruitment, due to the sedentary nature of their occupation (Ellam *et al.*, 1994), is also of concern. Given the high aerobic power required for a firefighter to perform in a safe and effective manner (Davis *et al.,* 1982), it is alarming that firefighters have been found to possess similar physiological profiles to the sedentary population (Lemon and Hermiston, 1977). Furthermore, the reduction in the ranges of joint motion, balance and physical endurance by 20-30% caused by personal protective equipment used within Fire & Rescue NSW (Taylor *et al.,* 2010a) indicates that the decline in physical fitness accompanying a sedentary lifestyle will be further exacerbated when firefighters are wearing protective equipment.

Changes in occupational management, and roles within health and safety, have proven to offer numerous benefits for the organisational workplace (Shannon *et al.* 1997), especially towards the implementation of proactive measures such as pre-work functional screening procedures and the subsequent decline in injury rates (Nassau, 1999). Thus, there is a clear need for valid screening tests that represent the trade-specific duties of individuals involved in physically demanding occupations. Given the current Fire & Rescue NSW physiological employment standards have not been based upon a rigorous evaluation of the trade-specific duties of contemporary firefighters, this research will aim to do this. However, these standards need to match the contemporary demands of fire fighting, to ensure the correct identification of individuals who are capable of performing the job which may, consequentially, help to reduce the high injury rates in firefighters.

1.1.3 Predicting job performance

When it is impractical to take precise measurements to classify an individual's ability in the workplace, predictive tools of performance can be used. For example, in the current project we could potentially identify variables to predict the functional performance of firefighters. Physically demanding occupations require trade-specific screening tests to enhance the recruitment of capable individuals (true positives), ones whom are most likely to possess the physical and physiological attributes necessary to perform the job in an efficient and safe manner. Thus, it is the aim of this research to produce methods by which the most capable firefighters are correctly identified. This tool can be applied to the fire-fighting workforce and indeed a hypothetical pre-employment screening test can be produced, illustrated in Figure 1.1.

In this illustration, the abscissa indicates screening test score while the ordinate indicates the job performance score, or rather the capability of one to adequately perform fire-fighting duties. Arbitrary thresholds have been hypothetically set, above which define those who have passed the nominal threshold for both the screening test and job performance. Thus, employers can identify potentially good firefighters (true positives), those who are in

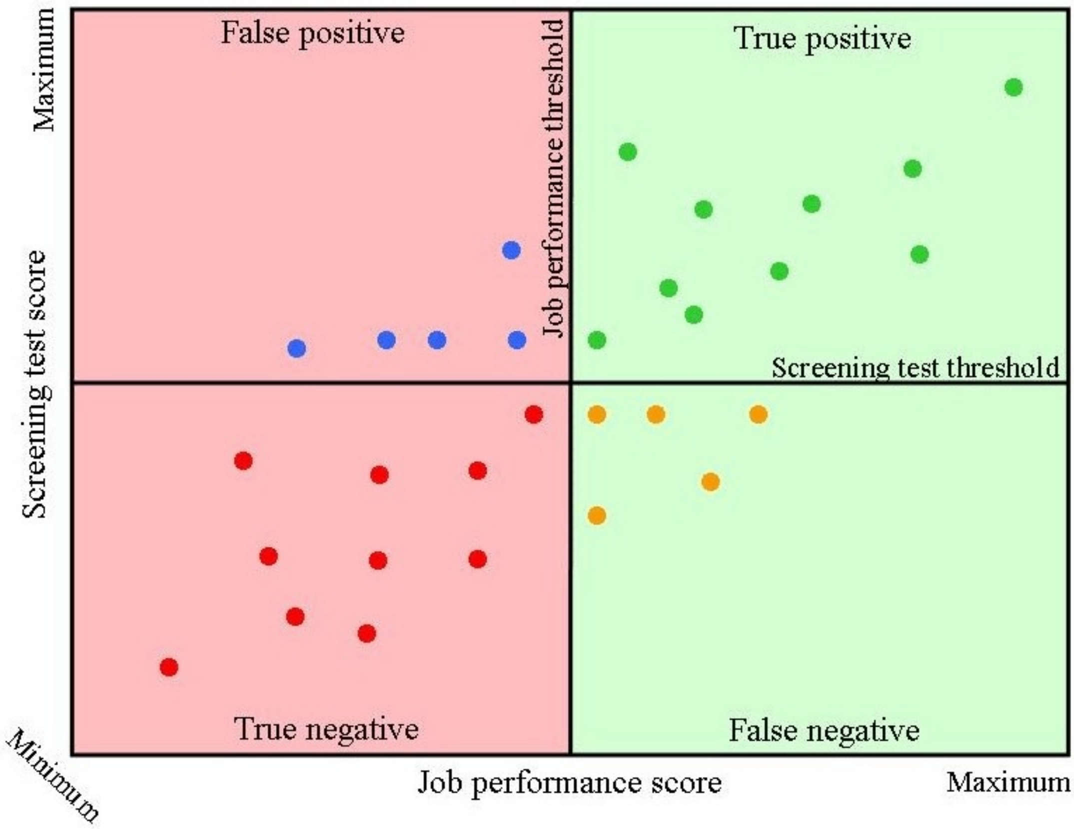

Figure 1.1: Hypothetical recruit screening from a pre-employment screening tool (ordinate) and from actual job performance ratings (abscissa). Scales range between minimum and maximum scores for each rating. The green shading defines individuals who possess the physical and physiological attributes consistent with the capable performance of fire-fighting duties. The red zone corresponds to those who do not currently possess these attributes.

the upper right quadrant and achieve an adequate score on the pre-employment screening test and are capable of performing the job. Employers will also try to minimise recruiting those incapable of performing the job, whether they pass a screening test (false positives) or not (true negatives). It is here that the employer must correctly identify those for whom the job is too physically demanding, whilst also minimising the failure to recruit potentially good firefighters, those capable of performing fire-fighting duties but are not passing the pre-employment screening test (false negatives). Thus, this research will focus on developing screening tools that contain an elevated sensitivity, tools that possess the potential to correctly identify capable firefighters.

If a predictive screening tool has a high sensitivity, it inherently becomes more reliable (providing reproducible outcomes) and valid (providing predictions of job performance). This reduces variability between job performance and the pre-employment screening test, maximising true positives and true negatives while minimising the number of false positive and false negatives. By developing legally defensible physiological employment standards, firefighters who are well suited to cope with the demands of fire-fighting will be identified. This will thereby increase the capability of potential firefighters, which may, consequentially, help to reduce the high injury rates in firefighters.

1.1.4 *Bona fide* physiological employment standards

In the modern day workplace, *bona fide* qualifications refer to employment procedures carried out in good and honest faith, that is to not discriminate on the basis of race, gender, age or disability (Clapp, 1999). To avoid being discriminatory, these procedures must ensure that selection processes are valid representations of critical duties derived from an extensive job analysis (Payne and Harvey, 2010). Fire & Rescue NSW currently uses a Physical Aptitude Test (PAT) and aerobic fitness test to screen firefighters as part of their annual recruitment process. This PAT includes a series of tasks designed to assess the physical capacity in relation to specific fire-fighting skills. However, a stringent re-evaluation of the physical demands of fire fighting must occur considering the ongoing changes in operations and equipment (Fire & Rescue NSW News, 2011).

A process of standard development and implementation that is deemed to be discriminatory can result in legal action (Constable and Palmer, 2000, Doherty *et al.*, 2007). For example, the case of Barr and Flannery versus the Treasury Board of the Department of National Defence (2006) resulted in the cessation of the eight-minute fire-fighting fitness standard in Canada. This standard was the cutoff score used to determine the minimum aerobic demand required to perform physically demanding fire-fighting duties. The eight-minute fire-fighting fitness standard was based on the job performance of healthy, young men. The plaintiffs (a woman and an elderly man) challenged this on the grounds that the standard was discriminatory, based on gender and age respectively. While the standard was declared to be implemented in good faith, and rationally linked to fire-fighting tasks, the employer failed to establish that it would undergo undue hardship if it employed the plaintiffs. An employer will undergo undue hardship if the accommodation of its employees comes at a substantial cost to the employer, is disruptive to the employer or it alters the organisational process by which the employer runs their organisation. Thus, the eight-minute fire-fighting fitness standard in Canada was deemed to not be a *bona fide* occupational requirement, and was removed from screening tests for firefighters.

Comparatively, Australian jurisdiction provides specific provisions for employment discrimination through direct and indirect discriminatory protocol. Specifically, employers in New South Wales must adhere to state and federal anti-discrimination laws which define direct discrimination as an occurrence whereby a person is treated unfairly due to their sex, race, colour, age, disability, or marital, homosexual, transsexual and/or associated status (Racial Discrimination Act, 1975; Anti-Discrimination Act, 1977; Sex Discrimination Act, 1984; Age Discrimination Act, 2004; NSW Department of Justice, 2012). Indirect discrimination is apparent when a person has been disadvantaged from a particular group yet could have been reasonably accommodated for in certain circumstances (NSW Department of Justice, 2012). For instance, if a disabled person cannot make it to work on time due to their disability and were refused employment, yet their employee could accommodate this discretion by organising the person's work to start and finish at different times (and this was reasonable to the continuing function of the organisation), the disabled person has been indirectly discriminated against (Anti-Discrimination Act, 1977; Disability

Discrimination Act, 1992; NSW Department of Justice, 2012). However, no discrimination would have been deemed to have taken place if the employer explored all instances whereby it was determined that the requirement for the disabled person to attend work in those hours was *reasonable in all circumstances* (Anti-Discrimination Act, 1977; NSW Department of Justice, 2012). This approach is similar to the European and Canadian methods of accommodation (European Union Council Directive, 2000; Canadian Human Rights Commission, 2007), and further displays the requirement for organisations to explore all avenues to accommodate job applicants unless the potential employee places an excessive burden (undue hardship) or present a safety risk on the employer (Hatfield, 2005).

Taken collectively, it is crucial scientific physiological employment standards encompass a combined legal approach, and focus on the performance of a range of disparate sub-groups, providing these participants are capable of the safe execution of the physically demanding duties, and complete such duties in the appropriate time period (Gledhill *et al.*, 2001; Jamnik *et al.,* 2010). This is especially pivotal for the critical nature of civilian lifesaving occupations (*e.g.* fire fighting). It is vital, therefore, that any physiological employment standards developed strive to meet the criteria the courts have established for determining a *bona fide* occupational requirement (Docherty *et al.,* 2007). To this author's knowledge, there does not appear to be direct exceptions for *bona fide* occupational requirements or a specific threshold for adverse impact cases in NSW or Australia. Notwithstanding this, abiding by these criteria is the preference of the legal counsel of an organisation within New South Wales (personal communication, Fire & Rescue NSW). It must be acknowledged that the responsibility for implementation and legal ramifications resides with the employer (Gledhill and Bonneau, 2001), however subject matter experts have the ability to enhance this process (Truxillo *et al.,* 2004). Thus, it is crucial the legal counsel and/or members of the employing organisation regularly communicate with scientific personnel (or the personnel developing the employment standards) prior to, and throughout the standard development to enhance legal defensibility (Jamnik *et al.,* 2010).

Therefore, employers must justify the following when defending physiological employment standards (Gledhill *et al.,* 2001):

(i) The standard was developed for the safe and efficient performance of the job.

(ii) The standard was developed in good and honest faith with a specific occupational purpose.

(iii) The standard is necessary for the accomplishment of this specific occupational purpose and has accommodated all potential and current employees whom do not place undue hardship on the employer.

These criteria were established following the 1999 Meiroin decision (Supreme Court of Canada, 1999), one that assesses the qualification of a *bona fide* occupational requirement (Jamnik *et al.,* 2011). Meiorin, a female firefighter, was dismissed by her employer after three years of service, due to her inability to meet a newly introduced aerobic fitness standard. Meiorin argued that the standard was discriminatory based on gender. The Supreme Court established that while the standard was developed in good faith for the *effective* performance of the job, the employer had failed to demonstrate that the standard was necessary to the *accomplishment* of the task. An employer must thus be able to demonstrate that the fitness screening requirements implemented are necessary for the accomplishment of the adequate performance of the job or otherwise leave themselves open to legal challenges. The current research will potentially facilitate the establishment of valid and legally defensible screening tests for use during recruit selection.

When establishing legally defensible (*bona fide)* physiological employment standards, there are a series of steps that are required to be undertaken by researchers. This stringent re-evaluation should have a critical focus on tasks that impose the most physiological burden upon the individual (Sothmann *et al.*, 1992a; Taylor *et al.*, 2010), so a task-specific test can replicate the full demands of the occupation (Bilzon *et al.*, 2001b, Garver *et al.*, 2005). This framework will focus on identifying individuals the employer can be most certain will perform the necessary trade-related tasks in a safe and efficient manner. This will ultimately help determine both the short- and long-term operational capability of the workforce. To ensure that the standards adhere to legislative law and are developed on the basis of enhancing the employer's occupational requirements framework (Gledhill and

Bonneau, 2001; Gledhill *et al.,* 2001), these steps have been identified and adapted from previous work (Gledhill and Bonneau, 2001; Gledhill *et al.,* 2001), and are summarised in Table 1.1, forming the basis for the current project.

This research will commence from Step Three (highlighted in yellow; Table 1.1), however the realms of this dissertation will end at Step Eleven. These steps focus on developing standards that actively reflect the demands of the job. Ultimately this framework should help to match the physical and physiological capabilities of firefighters with the demands of contemporary fire fighting, resulting in legally defensible (*bona fide)* physiological employment standards. This procedural summary assisted in the development of the research methods.

1.1.5 Aims of this project

This project was designed to develop *bona fide* physiological employment standards for firefighters. Three different investigations were performed. The first was a comprehensive review of the physical and physiological demands of fire fighting. The second was a field-based study involving quantification of the physical and physiological demands of the most essential and physically demanding trade tasks performed by firefighters. This determined the attributes necessary to perform fire-fighting duties in an optimal and safe manner. Thirdly, an evaluation of possible physiological screening tests for firefighters was investigated. This will potentially increase worker capability, and may minimise the risk of injury whilst facilitating the identification of predictive screening tools for Fire & Rescue New South Wales. It was the author's responsibility to develop appropriate methods, conduct the relevant data collection procedures and evaluate the project's outcomes, resulting in the subsequent sole construction of this dissertation. This dissertation forms part of a larger body of collaborative research between the University of Wollongong and Fire & Rescue New South Wales, which has been reported in separate technical reports (Taylor *et al.,* 2011; Groeller *et al.,* 2012; Taylor *et al.,* 2012). Furthermore, this dissertation does not include the validation, legal implementation and review of the developed physiological employment standards (Steps 12-19; Table 1.1). These validation phases are in the process of being compiled as separate technical reports.

Table 1.1: Framework for the development of *bona fide* pre-employment screening tests and physiological employment standards for physically demanding trades.

Project phase	Step	Description
0	1	Justify need for establishing employment standards
	2	Establish a Project Management Team
1	3	Familiarise research team with the trade
	4	Trade review and preliminary analysis of all tasks
	5	Identify the essential, physically demanding tasks
	6	Validate and approve the fire-fighting task list
	7	Employee survey: importance, difficulty, frequency of tasks
2	8	Characterise critical tasks: observe, measure, quantify
	9	Determine criterion fire-fighting tasks
	10	Validate and approve criterion fire-fighting tasks
3	11	Develop defensible physiological screening tests
	12	Standardise screening tests and administration
	13	Validate and approve screening tests
4	14	Evaluate validity and reliability of screening tests
	15	Acknowledge and approve performance standard development
5	16	Develop performance standards
	17	Validate and approve performance standards
	18	Implement pre-employment screening
6	19	Review the screening process and its outcomes: ongoing

Thus, the aims of this research were three-fold, as defined by the three research phases for this project:

(i) ***Phase 1 (Chapter One):*** Identification of the most physically demanding trade tasks of firefighters.

(ii) ***Phase 2 (Chapter Two):*** Quantification of the physical and physiological demands of fire fighting.

(iii) ***Phase 3 (Chapter Three):*** Developing physiological screening tests for contemporary firefighters.

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CHAPTER 2: IDENTIFICATION OF THE MOST PHYSICALLY DEMANDING TRADE TASKS OF FIREFIGHTERS.

2.1 INTRODUCTION

The demands of fire fighting coerce fire-fighting organisations to use pre-employment screening tests to identify potential employees who are well suited to coping with the physiological strain encountered within this occupation (Gledhill and Jamnik, 1992b). When screening applicants, employers aim to maximise the identification of potentially good employees (true positives or acceptances) and minimise the probability of failing to identify potentially good employees (false negatives or rejections). This attribute reflects the sensitivity of screening procedures (Malo *et al.*, 2006). However, screening tests must also correctly identify those for whom the job is too demanding (true negatives or rejections) while minimising the recruitment of inappropriate workers (false positives or rejections) and in doing so, become highly specific (Malo *et al.*, 2006). This screening approach is widely accepted as an adequate selection tool across numerous trades (Tipton *et al.,* 2012), including railroad workers (Rockey *et al.,* 1980), military personnel (Stevenson *et al.,* 1996), and for identifying cardiovascular risk factors in civilian populations (Han *et al.,* 1995). Whilst assessment tests take into account relative and absolute standards, individual (*e.g.* gender, stature) differences, predictive protocols and the effect of adverse impact, it is paramount these tests reflect job behaviours and actual task performance to ensure an accurate job analysis (Chapter One; Stevenson *et al.,* 1996; Payne and Harvey, 2010; Jamnik *et al.*, 2010; Tipton *et al.,* 2012). These tests are aimed at increasing the capability of the fire-fighting workforce, whilst simultaneously minimising the risk of injury for both employees and members of the community.

Through the development of *bona fide* physiological employment standards, it is possible to identify capable individuals by screening potential applicants. The critical legal and scientific steps within this process have been established (Table 1.1), and these steps provided the framework for the current project. The first phase in achieving this is to conduct a comprehensive review of the demands of fire-fighting trade tasks (Gledhill *et al.*, 2001), and herein lies the purpose of this study. The demands of fire fighting have been previously documented across numerous continents, including Europe (Sköldström, 1987; Bilzon *et al.*, 2001a), North America (Gledhill and Jamnik, 1992a) and Australia (Budd, 2001). However, the existing fitness standards for NSW firefighters are based on the demands of Canadian fire-fighting practise established 20 years ago (Gledhill and Jamnik, 1992a). Given the ongoing changes in operations and equipment (Fire & Rescue NSW News, 2011) since this time, this indicates a stringent re-evaluation of the physical demands of fire fighting, as performed in NSW, must occur. This will permit the quantification of these demands to take place, relative to the attributes necessary to perform the fire-fighting tasks in a safe and effective manner, and potentially facilitate the identification of predictive screening tools for firefighters.

When reviewing the physical demands of trade tasks, the first step in developing legally defensible physiological employment standards, it is critical to familiarise oneself with the trade in question. The second step is to review all physically demanding tasks. This must be carried out to understand the entire operational requirements of fire fighting (Gledhill, *et al.,* 2001). Then the essential, physically demanding tasks can be identified, which can be validated in turn by an employee survey. The essential, physically demanding tasks of fire fighting as performed within New South Wales, at least to the researcher's knowledge, have not been identified. Thus, by ascertaining the aforementioned information, further study of these trade tasks can be completed and assist in the development of screening tests for firefighters within New South Wales.

2.1.1 Aims of the study

The purpose of this study was to obtain a list of the essential, physically demanding tasks that firefighters perform during the course of their duties. This was conducted through visits to metropolitan and regional Fire Stations in order to familiarise the researcher with the trade. Once preliminary briefings, demonstrations and brief task reviews of all tasks were complete, an employee survey was administered to all permanent and retained firefighters who were invited to complete the survey to identify the most essential and physically demanding tasks performed by firefighters within NSW. Finally, a filtration process was conducted to obtain a valid list of the essential, physically demanding tasks.

2.2 METHODS

2.2.1 Fire Station visits

2.2.1.1 Subjects

One hundred and six firefighters (across all ranks) from eleven metropolitan, regional and retained Fire Stations participated in these interviews. This involved 68 permanent and 38 retained firefighters (Table 2.1). Participation in this study was voluntary and the subjects were free to withdraw at any time.

Since the author had a rudimentary understanding of the operational requirements of firefighters, then a full familiarisation was essential. Interviews were also held with firefighters (including Station Officers) as part of small discussion groups, as well as observations of firefighters performing some tasks, with two-four researchers (the author and other members of the Research Team) visiting several Fire Stations.

These included metropolitan (Alexandria, Bankstown, Botany, City of Sydney, Regentville), regional (Dubbo, Goulburn) and retained Fire Stations (Crookwell, Delroy, Helensburgh). These Stations were chosen by Fire & Rescue NSW Commanders such that the broadest range of fire-fighting experience was made available to the research team. Both permanent and retained firefighters were interviewed and this was dependant on location and Fire Stations. This Phase follows Steps 3-7 in the procedural summary from the framework for physical employment standards (Table 1.1).

2.2.1.2 Experimental procedures

In order to gain a full understanding of the various types of incidents firefighters face and the resultant trade tasks they undertake, the research team collated a series of questions that were asked on arrival at each of the Fire Stations. These questions were used to explore and obtain the necessary information to familiarise the research team with the occupation of fire fighting:

- What are the types of incidents that you attend from this Station?
- Which are the most physically demanding incidents?
- What aspects of these incidents cause them to be physically demanding?

Table 2.1: Summary of 106 firefighters interviewed during this Phase of the research.

Fire Stations	P:FF	P:QFF	P:SFF	P:LFF	P:SO
Alexandria[1-P]		4	3	1	2
Bankstown[2-P]		3	3		2
Botany[2-P]		3	2		2
City of Sydney[3-P]	7	3		2	3
Dubbo[1-P]	1	2	1		1
Goulburn[1-P]	3		3		1
Regentville[2-P]	2	4	5		2
Warrawong[1-P]			3		1
Fire Stations	**R:FF<5**	**R:FF5-10**	**R:FF10-15**	**R:FF>15**	**R:C**
Crookwell[1-R]	2	4			2
Dubbo[1-R]		2	1	2	2
Delroy[1-R]	2	1		2	4
Goulburn[1-R]	2	1	3	2	1
Helensburgh[1-R]	2	2			1

Notes: Superscript numbers denote platoons interviewed. Permanent Stations are indicated with 'P' and retained-only with 'R'. ***Abbreviations:*** P:FF = permanent firefighter (0-3 years experience), P:QFF = permanent qualified firefighter (3-6 years), P:SFF = permanent senior firefighter (>6 years), P:LFF = permanent leading firefighter, P:SO = permanent Station Officer, R:FF<5 = retained firefighter (<years experience), R:FF5-10 = retained firefighter (5-10 years), R:FF10-15 = retained firefighter (10-15 years), R:FF>15 = retained firefighter (>15 years), R:C = retained Deputy Captain or Captain.

- Let us explore the following incident: *Incident X*
  - walk us through this incident
  - what happens when:
    - the call-out occurs?
    - you are in the appliance (fire truck)?
    - you first arrive at the incident?
  - what happens during the course of the incident?
  - what recovery actions are needed?
- Which are the most critical tasks and why?
- Is this task an individual or a team task?
  - If this is an individual task, is the performance most reliant on fitness or skill?
  - If it is a team task, is the performance of the task heavily influenced by team member level of fitness or team member level of skill?
- Do task demands decline significantly as you become more familiar with each task?
  - If yes, how does this occur?
  - Are there any tasks which slow down your response time, and if so why?
- Think about any injuries that you have experienced as a firefighter:
  - what were you doing at the time of the injury?
  - describe the injury
  - what was the cause of the injury?
  - is this a common injury?

The tasks identified through this process were then classified into lists that defined the work-related demands placed upon firefighters under each of three Fire & Rescue NSW operational phases:

Readiness: preparation and training.

Response: actions necessary when responding to an incident, call-out or an alarm:

- response to the initial alarm

- actions involving donning and checking personal protective equipment
- action on arrival at an incident
- fighting the fire.

Recovery: actions following the response:

- salvage: unknown victims, fully extinguish fire, checking hazards and structural integrity, removing debris
- recovery of equipment: recovery and replenishment, and recovery at the Station.

In addition, these tasks were then pooled into the topics defined by the Training Needs Analysis of Fire & Rescue NSW (Endeavour Training and Development, 2010). This analysis was compiled to identify tasks performed by contemporary firefighters through a series of interviews with subject-matter experts. These tasks included all firefighter duties, which aimed to enhance recruit processes and on-the-job training. Included in these analyses were firefighters, stations officers, duty commanders, training staff and education development staff.

However, greater detail of the aforementioned tasks was required. This provided each task to be classified into codes dependant on the incident, allowing for further understanding of each task and laying a foundation for further progress into the subsequent research phases.

2.2.1.3 Consolidated list of trade tasks

Since the trade task list resulted in an extensive list of tasks, it was necessary to fine tune this preliminary list into a manageable subset of essential items to form the basis of the next step of this research phase. This occurred through a task validation and approval process involving the Project Management Team established to oversee this project. This Team was made up of the author, fellow University researchers (Research Team) and Senior Officers and Managers from Fire & Rescue NSW. A face-to-face focus group meeting with members from these teams, of which all Senior Officer's had greater than 10 years operational fire-fighting experience. To assist with the task validation and approval process, the focus group was asked to provide an opinion on the preliminary trade task list with regards to the following:

(a) Inclusion/exclusion of the task based on the physical demands of the task.

(b) Inclusion/exclusion of the task based on shared physical demands existing between two or more tasks (resulting in unnecessary duplication).

Following deliberations of this Team, a suitable subset of tasks was selected from this preliminary list of trade tasks to assist in the creation of a survey for firefighters. The purpose of this survey was to further validate the tasks chosen, to discover any tasks not yet identified and quantify the importance, frequency, physical effort and duration of each task (Sharkey and Davis, 2008).

It is well known the exaggeration risk when individuals are asked to rate the frequency, significance and duration of some physical activities (Aadahl and Jørgensen, 2003; Rzewnicki *et al.*, 2003), or the delivery of socially acceptable responses (Klesges *et al.*, 1990; Moti *et al.*, 2005). Thus, prior to the assembly of this preliminary list, two tasks were included as deliberate calibration tasks as requested by the Management Team. These tasks were deemed by the Management Team to be low-effort tasks. These tasks were the bowling out of a 38-mm hose and the use of the 4.6-m ladder. Therefore, the research team believed exaggerated survey responses would be minimised if respondents reported these tasks as possessing a low physical demand (effort).

Respondents were also asked questions regarding the physical capacity they believed to be required of a firefighter. For instance, they were asked whether they had ever found their ability to perform certain tasks was limited by some aspect of their physical capacity (*e.g.* strength, endurance or cardiovascular fitness). Given the aim of this study was to produce a manageable list of the essential, physically demanding tasks that firefighters perform during the course of their duties, it was predicted certain exclusion and inclusion criteria would be established at a later stage of this project. It was believed these questions would assist with this process.

Pilot surveys were administered to both Wollongong Fire Station (14 permanent firefighters) and Balgownie Fire Station (7 retained firefighters) prior to the release of the final electronic and paper surveys. These pilot surveys allowed us to finetune various firefighting terms used in the questions and to evaluate the utility of both the electronic and printed versions across both employment classifications.

2.2.2 Survey of firefighters

One thousand and eleven firefighters participated in the survey, all of whom provided informed consent. All procedures were approved by the Human Research Ethics Committee, University of Wollongong (HE11/229). This survey was administered to all permanent and retained firefighters across NSW to further assist in the task validation process. Since all permanent employees of Fire & Rescue NSW have electronic mail accounts, each permanent firefighter was invited to participate in an online survey concerning the approved list of physically demanding trade tasks. Following advice from the Management Team, 3,660 paper surveys were delivered across the retained Fire Stations within the State (244 Stations) along with reply-paid envelopes. The reason for this was that retained employees are infrequent users of their electronic mail accounts.

Both surveys were anonymous, with permanent respondents being identified only through the use of subject codes generated by the survey computer programme (SurveyMonkey.com $_{TM}$, CA, USA). Firefighters were given 33 days to answer the survey, with responses downloaded in the form of a Microsoft Excel 2007$_{TM}$ spreadsheet. The paper survey was a copy of the online survey, the only difference being that the respondents had to enter data or tick boxes, rather than choose from a drop-down menu of options. These data were then manually entered into a separate Microsoft Excel 2007$_{TM}$ spreadsheet to perform various statistical analyses and comparisons not feasible within the scope of the SurveyMonkey.com $_{TM}$ data output. All firefighters were sent an information package and the complete survey (Appendix One).

Firefighters were asked to record their age, sex, experience and employment classification. It was deemed important, at this stage of the project, to pursue these detailed analyses given the legal ramifications of a vague job analysis (Barr and Flannery vs Department of Defence, 2006). For instance, in the case of Barr and Flannery vs Department of Defence (2006), the implemented eight-minute circuit standard was adjudicated to be not legally defensible, as the scientific process employed did not comprise enough women or older individuals. Whilst it is acknowledged that job experience, and as a function, employment classification may play a role in variable frequency ratings (Landy and Vasey, 1991; personal communication Fire & Rescue NSW), it was necessary to provide a detailed job analysis comprising of a range of sub-groups to ensure enhanced legal defensibility (Gledhill *et al.,* 2001). Indeed, job analyses by age and experience level have been deemed necessary to determine physiological employment standards for correctional officers (Jamnik *et al.,* 2010). It should be noted here that certain employment classifications within Fire & Rescue NSW (*e.g.* Station Officer) require a particular level of experience (*e.g.* ten years), thus it seemed appropriate to pursue these analyses (personal communication, Fire & Rescue NSW).

When questions were asked concerning task difficulty and importance, it was the choice of the researcher to base the options upon a ten-point scale (*e.g.* Borg, 1962a, 1962b), since this was thought to be more familiar to a wider range of respondents (Dawes, 2008). However, after consultation with the Management Team and fellow researchers, it was decided that a five-point scale would be used. Indeed, the Management Team appreciated the work of Dawes (2008), and acknowledged that it was crucial for the survey to associate with a wide range of respondents. It was concluded that a five-point scale would be easier for the firefighters to evaluate trade task importance and physical effort given that such a large number of firefighters would be completing the survey and the limitations completion time placed upon these employees during work hours. In addition, five-point scales have been previously used to detect the severity of depression (Blacke *et al.,* 1998), pain (Levine *et al.,* 1993), economic performance importance (Slack, 1994) and the importance and effort of tasks performed by correctional officers (Jamnik *et al.,* 2010).

For evaluating trade task importance and physical effort the rating scale was:

1 = least

2 =

3 = moderate

4 =

5 = most

Respondents were asked to report the importance (scale: 1 to 5), frequency (scroll down options and open scale), physical effort (scale: 1 to 5) and duration (scroll down options and open scale) of each task (Appendix One). Thus, there would be a slim likelihood of exaggerated survey responses if the respondent positioned each of these tasks towards the bottom of the rankings (*e.g.* scores closer to 1) for physical effort (demand). Moreover, bias may also be revealed in the reporting of the frequency of these tasks relative to the other activities. Respondents were also asked if they experienced physical limitations (*e.g.* endurance, strength) during the performance of these tasks. This would possibly reveal the more effortful (*e.g.* scores closer to 5) tasks, under the assumption that more physically demanding tasks would elicit an excessive limitation on the firefighter's physiological capabilities. It was assumed this approach could also serve as support towards the validation of the ratings for physical effort. For the online survey, frequency ranged from fourteen options per annum: 0 through to 9 in one unit increments, 10-15, 16-25, 26-50, and more than 50. Duration ranged from nine options: 0-30 sec, 1 min , 2-5 min, 6-10 min, 11-20 min, 21-30 min, 31-60min, 1-2 hrs and 2-5 hr. Thus, performance across various criteria could be given a rank for each criteria respectively.

2.2.3 Data analysis

Descriptive statistical procedures were used to provide a quantitative summary of all measures and observations combined from both the online and paper surveys. Data were reported as means, standard deviations and response ranges. Each of the trade tasks analysed for the entire sample of firefighter responses was assigned a mean ranking between one and five for both task importance and task physical effort (demand). Statistical differences ($p < 0.05$) between the responses of permanent and retained firefighters were also analysed. Multiple-point scales were used to evaluate task performance frequency and task duration.

2.3 RESULTS

2.3.1 Fire Station visit results

Table 2.2 lists the physically demanding tasks performed by firefighters in their course of duty. These have been classified into the three operational stages of fire fighting (readiness, response and recovery). This categorisation assisted the integration and the collation of information in this research phase.

2.3.1.1 Task classification using the training needs analysis codes

Following the classification of tasks dependant on their operational phases, tasks were then grouped into categories as defined by the training needs analysis (Endeavour Training and Development, 2010). Each task was classified into codes dependant on the incident, allowing for further understanding of each task and laying a foundation for further progress into the subsequent research phases (Appendix Two).

2.3.1.2 Consolidated list of trade tasks

Listed below is the subset of essential task items to form the basis for the next step of this research phase. This occurred through a task validation and approval process involving the Management Team established to oversee this project.

- Bowling out 70-mm hose
- Bowling out 38-mm hose
- Locating hydrant, carrying equipment and getting water to appliance
- Coupling/uncoupling hoses
- Dragging 70-mm charged hose across a horizontal surface
- Dragging 38-mm charged hose across a horizontal surface
- Dragging 38-mm charged hose up a stairway
- Stair climbing with personal protective equipment, breathing apparatus and charged hose
- Stair climbing with personal protective equipment, breathing apparatus, high rise pack, axe and halligan tool

Table 2.2: The physically demanding trade tasks performed by firefighters, classified within the three operational stages of fire fighting. PPE= Personal protective equipment; BA= Breathing apparatus; HAZMAT; Hazardous Materials.

Operational stage	Trade task
Readiness	Appliance re-stow
	Performing simulation drills
Response	Rescue firefighter/victim while wearing PPE and BA
	Dragging and holding charged hose
	Dragging charged hose through buildings
	Prolonged holding of charged hose: 38 mm and 70 mm
	Rolling out uncharged hose lines
	Stair climbing with PPE, BA and charged hose
	Stair climbing with PPE, BA, charged hose, high rise fire fighting, axe and halligan tool
	Lifting and carrying heavy objects
	Using power saw (cutter) to gain access
	Prolonged chain saw use following storms
	Breaking through or jumping over fences and obstacles
	Carrying rapid intervention kit (RIK) for gaining entry
	Sledge hammer carry and use
	Moving slabs of concrete following building collapse
	Removal of vehicle doors and roofs following accident
	Finding hydrant and carrying the necessary equipment
	Coupling and uncoupling hoses
	Carrying power generator (two-person lift)
	Hydraulic hose unwind and rewind
	Carrying ventilation fan up stairs (two-person lift)
	Moving victims with Stokes Litter (cliff rescue)
	Bush: prolonged walking in bushland carrying cordage pack

	Bush: digging fire break using McLeod Tool (hoe)
	Bush: dragging charged hose (3-4 lengths; 25 mm or 38 mm) for 100 metres on hilly, sloped, uneven surfaces
	Bush: prolonged Stokes Litter carry: 1 km on rough terrain
	Lifting and moving heavy loads when wearing HAZMAT clothing
	Prolonged walking (up and down inclines) in HAZMAT clothing
	Lifting and carrying heavy objects
	Prolonged crawling, kneeling, crouching, squatting: fire attack
	Prolonged crawling, kneeling, crouching, squatting: search
	Prolonged crawling, kneeling, crouching, squatting, dragging: rescue
	Lifting, positioning and stabilising spreaders
	Lifting, positioning and stabilising shears
	Using air-operated (hydraulic) tools
	Carrying hydraulic pump or Davey pump (two-person lifts)
	"Draughting" with suction hose attachments to remove water from flooded location or to obtain water from dam
	Ladder use: removal, replacement, under running
	Ladder stabilisation: usually 2-3 people, but sometimes 1 person
	Rescue via ladder: two-person
	Rescue via ladder with Stokes Litter
	Rescue via stairs
	Dragging charged line of hose onto and throughout a ship
	Prolonged static work (*e.g.* holding victim's head)
	Carrying block sets and tools to stabilise vehicle
	Moving people (often obese) using canvas/salvage sheets

	Using crowbar (2-metre bar) to lever open vehicle doors/bonnet
	Fire fighting and HAZMAT tasks in tunnels: long walks
Recovery	Salvage and overhaul: internal
	Salvage and overhaul: external
	Rolling lines of uncharged 38-mm and 70-mm hose
	Appliance re-stow
	Shovelling debris or liquids in splash or HAZMAT clothing
	Pulling down ceiling using ceiling hook
	Carrying Stokes Litter to return to ambulance or appliance
	Under running wet hoses and hoisting hoses up the whips
	Flaking hose trays and loading onto appliance
	Pushing appliance shelves into position when on a slope

- Prolonged use of charged hose: 38 mm (1 person)
- Prolonged use of charged hose: 70 mm (2 people)
- Prolonged crawling, kneeling, crouching, squatting: fire attack
- 4.6-m "Jumbo/Little Giant" ladder use: gaining access and/or rescue/salvage work
- 10.5-m ladder use: under running, stabilisation
- 10.5-m ladder use: 2 person removal and replacement
- Rescue via ladder (2 person)
- Rescue victim via stairs (2 person)
- Rescue firefighter while wearing personal protective equipment, breathing apparatus (1 person)
- Rescue victim while wearing personal protective equipment, breathing apparatus (2 person)
- Moving victims with salvage sheets or Stokes litter
- Using spreaders and shears
- Prolonged static work (*e.g.* holding victim's head)
- Using sledge hammer to gain entry
- Carrying ventilation fan up stairs (2 person)
- Carrying Davey pump (2 person)
- Pulling down ceiling using ceiling hook
- Hazmat: prolonged walking and manual handling in fully encapsulated suit
- Tunnel search and rescue
- Bush: prolonged walking with cordage pack or Stokes Litter
- Bush: dragging charged hose on hilly, sloped, uneven surfaces
- Bush: digging fire break (McLeod Tool)

2.3.2 Survey results

Invitations to participate in the survey were sent to all 6,781 firefighters currently employed by Fire & Rescue NSW (NSW Fire Brigades, 2010). 745 firefighters completed the online survey, with 266 firefighters completing the paper survey. In total, 1,011 respondents (14.9% of all firefighters) attempted the survey (mean age 40.6 y (range: 18-74 y) with 22 firefighters withdrawing. Respondents were analysed within each employment category, whereby 717 permanent firefighters completed the survey (21.4% of this employment category), along with 272 retained firefighters (7.9% of this employment category). These individuals had worked with Fire & Rescue NSW for an average duration of 12.8 years (range: 1-49 y). These data are summarised within Table 2.3, with breakdowns provided according to both gender and employment classification (Permanent versus Retained). Women responded in excess of their employment representation (3.2%; (NSW Fire Brigades, 2010), providing 5.2% of all responses, with retained firefighters making up 27.5% of all respondents.

Within both the permanent and retained employment classifications, firefighters can be grouped into each of two sub-divisions (Metropolitan and Regional), or under the role of Operational Support. Responses were received from firefighters within each of these five groups, and the proportional representation of each group is summarised in Figure 2.1 (actual survey returns: permanent metropolitan = 575, permanent regional = 102, retained metropolitan = 62, retained regional = 210 and operational support = 40). Table 2.4 provides a detailed age and experience breakdown of these firefighters. Operational support staff was the oldest employment group (44.8 y) while permanent: metropolitan staff was the youngest (39.0 y). These two employment classification also have contrasting experience levels, with the lowest (3.3 y) and highest (11.1 y) mean experience respectively.

Table 2.5 provides a summary of the respondents according to employment classification, including the nine official permanent roles and six groups of retained firefighters based on experience levels. These are then displayed within each classification and gender. Table 2.6 provides a detailed summary of the distribution of respondents by age and across genders. Distribution of 50-60 year olds was well represented with 16.9% of the total workforce. Reflective of the mean age of all respondents (40.6 y) is the representation of 30-40 and 40-50 year olds, with 33.4% and 32.2% of all responses respectively. Females had an equal or greater representation of their overall distribution in the current workforce in all age groups except the 50-60 and > 60 year old groups.

Table 2.3: The age (years) and experience as a firefighter (years) of all respondents, with gender and employment classification breakdowns.

	Age (mean)	Standard deviation	Experience (mean)	Standard deviation
Overall	40.6	9.7	12.8	9.5
Males	40.7	9.8	13.0	9.6
Females	38.3	7.5	8.8	6.1
Permanent	40.1	8.7	13.3	9.1
Retained	41.9	11.9	11.4	10.4

Table 2.4: The age (years) and experience as a firefighter (years) within the five major employment breakdowns.

	Age (mean)	Standard deviation	Experience (mean)	Standard deviation
Permanent: Metropolitan	39.0	8.7	11.1	12.1
Retained: Metropolitan	39.1	11.6	5.9	7.0
Permanent: Regional	44.6	7.7	5.8	6.2
Retained: Regional	42.7	11.9	8.8	10.0
Operational support	44.8	7.4	3.3	2.9

Note: These data are influenced by transfers, with some firefighters working across all classifications.

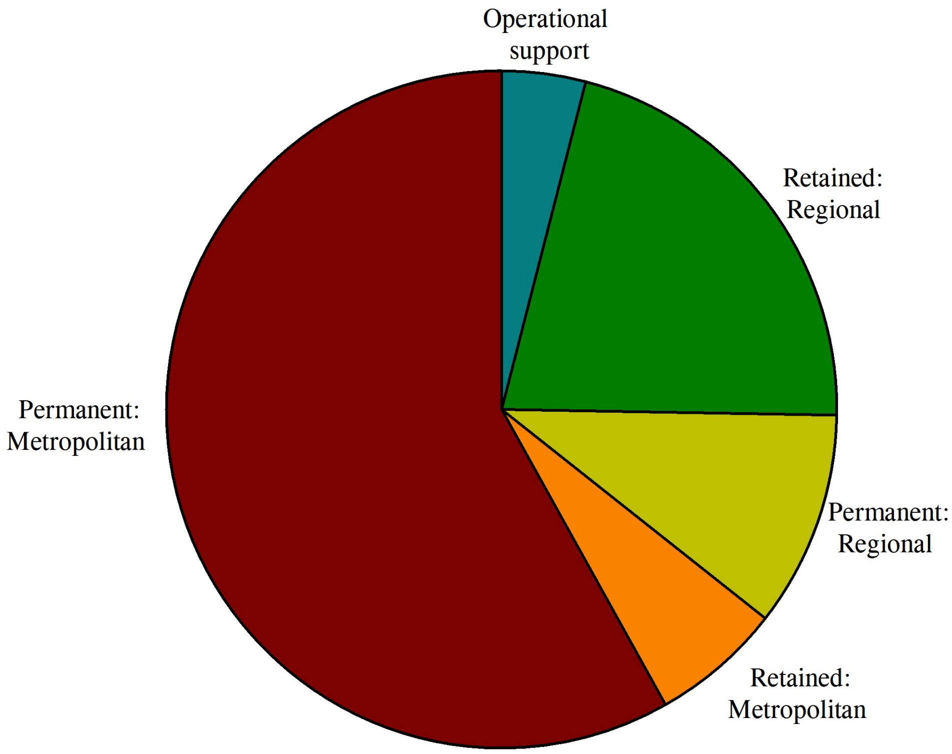

Figure 2.1: Distribution of respondents on the basis of employment classification. Survey returns: Red: permanent metropolitan = 575 respondents, Yellow: permanent regional = 102, Orange: retained metropolitan = 62, Green: retained regional = 210 and Blue: operational support = 40.

Table 2.5: Summary of respondents according to employment classification (permanent versus retained), ranks within each classification and gender. Data are normalised to the total number of respondents (percent total), to the number of respondents from each classification (percent class) and to the total number of male and female respondents.

Rank	Count	Percent total	Percent class	Male count	Percent male	Female count	Percent female
P: FF	61	6.2%	8.5%	56	6.0%	5	9.8%
P: QFF	169	17.1%	23.6%	156	16.6%	13	25.5%
P: SFF	252	25.5%	35.1%	233	24.8%	19	37.3%
P: LFF	6	0.6%	0.8%	6	0.6%	0	0.0%
P: SO	184	18.6%	25.7%	177	18.9%	7	13.7%
P: I	26	2.6%	3.6%	26	2.8%	0	0.0%
P: Super	8	0.8%	1.1%	8	0.9%	0	0.0%
P: C Super	0	0.0%	0.0%	0	0.0%	0	0.0%
P: Exec	0	0.0%	0.0%	0	0.0%	0	0.0%
R: FF<5	95	9.6%	34.9%	93	9.9%	2	3.9%
R: FF 5-10	49	5.0%	18.0%	46	4.9%	3	5.9%
R: FF 10-15	25	2.5%	9.2%	24	2.6%	1	2.0%
R: FF >15	32	3.2%	11.8%	32	3.4%	0	0.0%
R: Dep Capt	34	3.4%	12.5%	33	3.5%	1	2.0%
R: Capt	34	3.4%	12.5%	34	3.6%	0	0.0%

Notes: P: FF = permanent firefighter, P: QFF = permanent qualified firefighter, P: SFF = permanent senior firefighter, P: LFF = permanent leading firefighter, P: SO = permanent Station Officer, P: I = permanent Inspector, P: Super = permanent Superintendent, P: C Super = permanent Chief Superintendent, P: Exec = permanent Executive, R: FF<5 = retained firefighter with less than five years experience, R: FF 5-10 = retained firefighter with 5-10 years experience, R: FF 10-15 = retained firefighter with 10-15 years experience, R: FF >15 = retained firefighter with more than 15 years experience, R: Dep Capt = retained Deputy Captain, R: Capt = retained Captain.

Table 2.6: Distribution of respondents by age and across genders (completed surveys).

	All	Male	Female
Total count	989	938	51
Percent all responders	100.0%	94.8%	5.2%
<30 years old	141	134	7
Percent	14.3%	14.3%	13.7%
30-40 years old	330	311	19
Percent	33.4%	33.2%	37.3%
40-50 years old	318	294	24
Percent	32.2%	31.3%	47.1%
50-60 years old	167	166	1
Percent	16.9%	17.7%	2.0%
>60 years old	30	30	0
Percent	3.0%	3.2%	0.0%

Note: Some individuals did not declare either their age or gender.

The four subjective ratings (importance, physical effort, frequency and duration) were statistically analysed for all thirty-one essential, physically demanding tasks. These ratings were both collectively treated, and sub-divided into each of the four principal employment classifications: permanent metropolitan, permanent regional, retained metropolitan, retained regional. Values are expressed as the mean and standard deviation. To determine relationships between the values of the measured variables, statistical significance was accepted for $p < 0.05$. These analyses allowed for an evaluation of the probability that firefighters from different employment classifications would likely be exposed to different subsets of tasks, and different task performance frequencies. This was critical given the inappropriateness of basing pre-employment screening tests on physically demanding tasks that a group of workers would not encounter during the course of their employment. Thus, this analysis provided a more rigid justification of the fire-fighting tasks selected for a more detailed investigation. Whilst such an extraction of data reduces the sample size upon which interpretation may be based, the large sample of survey returns for each employment classification (range: 62-575) indicates these sub-divisions are reliable measures to express these subjective rating procedures.

2.3.2.1 Importance

The ratings of trade-task importance (criticality) for each of the thirty-one essential, physically demanding tasks, as defined by each employment classification, are summarised in Table 2.7. A superscript "⋆" has been positioned in the column for the permanent firefighters to show that data in the corresponding cell of the adjacent column (retained firefighters) differ significantly ($p < 0.05$). Rescuing a fellow firefighter (mean 4.86, SD 0.50) was deemed the most important trade task, followed closely by rescuing a victim (mean 4.79, SD 0.55). Trade tasks that included stair climbing were found to be less important overall for regional firefighters compared to metropolitan firefighters.

2.3.2.2 Difficulty

The ratings of trade task difficulty for each of the thirty-one essential, physically demanding tasks, as defined by each employment classification, are summarised in Table 2.8. A superscript "⋆" has been positioned in the column for the permanent firefighters to

Table 2.7: Ratings of trade task importance (scale 1-5) under employment classification.

Task	P-Metro	R-Metro	P-Region	R-Region
Rolling out 70 mm	4.0	3.8	3.8	3.6
Rolling out 38 mm	4.2	4.2	3.9	3.9
Hydrant: locating and connecting	4.5	4.5	4.4	4.4
Coupling hoses	3.9	3.9	3.5^{*}	3.9
Drag 70-mm charged hose: flat	3.8	3.6	3.5	3.5
Drag 38-mm charged hose: flat	4.3^{*}	4.0	4.0	3.8
Drag 38-mm charged hose: stairs	4.3^{*}	4.0	4.0^{*}	3.6
Stairs: PPE, BA, hose	4.5^{*}	4.3	4.3^{*}	4.0
Stairs: PPE, BA, hose, tools	4.3	4.1	4.1^{R}	3.6
Using 38 mm	4.2	4.1	3.9	4.0
Using 70 mm	4.0	3.9	3.8	3.8
Fire attack	4.3	4.0	4.1^{*}	3.8
Ladder use: 4.6 m	3.7	4.0	3.4	3.6
Ladder use: 10.5 m: 1 person	4.2^{*}	3.9	4.0	3.6
Ladder use: 10.5 m: 2 people	4.0	3.8	3.7	3.5
Rescue victim: ladder - 2 people	4.5	4.3	4.3^{*}	4.0
Rescue victim: stairs - 2 people	4.6	4.5	4.3	4.2
Rescue FF: 1 person	4.9	4.9	4.9	4.7
Rescue victim: 2 people	4.9	4.8	4.8	4.6
Moving victim	4.0	4.3	4.1	4.0
Using spreaders and shears	4.2	4.4	4.2	4.2
Prolonged static work	3.9^{*}	4.3	3.8^{*}	4.2
Using sledge hammer	3.8	3.5	3.6^{*}	3.3
Carry: ventilation fan (stairs): 2 people	3.4^{*}	3.8	3.3	3.2
Carry: Davey pump: two people	3.2^{*}	3.6	3.1	3.2
Pulling down ceiling	3.3	3.5	3.2	3.2
Hazmat: walking, manual handling	3.8	4.0	3.9	4.0
Tunnel search and rescue	3.7	3.8	3.6	3.7
Bush: walking, manual handling	3.3	3.4	3.2	3.3
Bush: drag charged hose	3.9	3.7	3.8	3.6
Bush: digging fire break	3.8	3.8	3.8	3.7

Notes: P-Metro = permanent metropolitan; R-Metro = retained metropolitan; P-Region = permanent regional; R-Region = retained regional. Shading: red >4.5, orange: 3.5-4.5, white: <3.5. Superscripts denote statistical differences (⋆).

Table 2.8: Ratings of physical effort (scale 1-5) grouped by employment classification.

Task	P-Metro	R-Metro	P-Region	R-Region
Rolling out 70 mm	3.1	3.0	2.9*	2.7
Rolling out 38 mm	2.6*	2.5	2.4*	2.3
Hydrant: locating and connecting	3.4*	3.0	3.3*	2.7
Coupling hoses	2.8	2.2	2.8*	2.2
Drag 70-mm charged hose: flat	4.4	4.5	4.2*	4.0
Drag 38-mm charged hose: flat	3.5	3.7	3.4	3.5
Drag 38-mm charged hose: stairs	4.3	4.3	4.1*	4.0
Stairs: PPE, BA, hose	4.6	4.6	4.5*	4.1
Stairs: PPE, BA, hose, tools	4.4	4.5	4.3*	4.2
Using 38 mm	3.6	3.7	3.4	3.6
Using 70 mm	4.3	4.2	4.2*	4.1
Fire attack	3.9	3.9	4.0	3.8
Ladder use: 4.6 m	3.0	3.2	3.0*	3.1
Ladder use: 10.5 m: 1 person	4.0	3.9	3.8*	3.6
Ladder use: 10.5 m: 2 people	3.7	3.7	3.3*	3.4
Rescue victim: ladder - 2 people	4.4	4.3	4.0*	3.9
Rescue victim: stairs - 2 people	4.3	4.3	4.1*	4.1
Rescue FF: 1 person	4.9*	4.7	4.8*	4.5
Rescue victim: 2 people	4.7	4.6	4.6*	4.3
Moving victim	3.7*	4.2	3.8	3.7
Using spreaders and shears	3.8	3.8	3.8*	3.6
Prolonged static work	2.7*	3.2	3.0*	3.1
Using sledge hammer	3.6	3.5	3.6*	3.3
Carry: ventilation fan (stairs): 2 people	3.6	3.7	3.5*	3.3
Carry: Davey pump: two people	3.4	3.6	3.3	3.2
Pulling down ceiling	3.2	3.0	3.3	3.1
Hazmat: walking, manual handling	4.1	4.3	4.2	4.2
Tunnel search and rescue	3.7*	4.1	4.0	3.8
Bush: walking, manual handling	3.4	3.6	3.4	3.5
Bush: drag charged hose	4.2	4.2	4.2	4.1
Bush: digging fire break	3.8	3.8	3.8	3.7

Notes: P-Metro = permanent metropolitan; R-Metro = retained metropolitan; P-Region = permanent regional; R-Region = retained regional. Shading: red > 4.5, orange: 3.5-4.5, white: 3.1-3.5, green: < 3.1. Superscripts denote statistical differences (⋆).

show that data in the corresponding cell of the adjacent column (retained firefighters) differ significantly ($p < 0.05$). Similar to its importance ranking, rescuing a firefighter (mean 4.78, SD 0.58) was also found to be the most difficult trade task, followed closely by rescuing a victim (mean 4.56, SD 0.70) and the stair climb whilst wearing the personal protective ensemble, breathing apparatus and carrying a 38-mm hose (mean 4.47, SD 0.80). The easiest task was rolling out a 38-mm hose (mean 2.49, SD 0.96), followed by coupling hoses (mean 2.56, SD 1.14). Permanent firefighters (Metropolitan: 3.40 and Retained: 3.30) rated difficulty of the location and connection of a hydrant higher than retained firefighters (Metropolitan: 3.00 and Retained: 2.70). Rankings of importance, overall, were significantly higher for permanent regional employees compared to retained regional employees.

2.3.2.3 Frequency

The ratings of trade-task frequency, as defined by each employment classification, are summarised in Table 2.9. A superscript "⋆" has been positioned in the column for the permanent firefighters to show that data in the corresponding cell of the adjacent column (retained firefighters) differ significantly ($p < 0.05$). Permanent firefighters overall reported the performance of more trade tasks than retained firefighters. Those tasks that were reported as the easiest (coupling hoses and rolling out 38-mm hose) across all employment classifications were also reported as the most frequently performed tasks (mean 39.98, SD 31.69 per annum; mean 29.26, SD 19.79 per annum) respectively. The least frequently performed tasks across all employment classifications were the tunnel search and rescue (mean 1.39, SD 4.34 per annum), rescuing a firefighter (mean 1.46, SD 4.82 per annum) and rescuing a victim (mean 2.50, SD 5.44 per annum). Rankings of frequency were significantly higher overall for permanent regional employees compared to retained regional employees. This trend was also evident for permanent metropolitan employees compared to permanent regional employees.

2.3.2.4 Duration

The ratings of trade-task duration for each of the thirty-one essential, physically demanding tasks, as defined by each employment classification, are summarised in Table 2.10. A

Table 2.9: Task performance frequencies (*per annum*) under employment classification.

Task	P-Metro	R-Metro	P-Region	R-Region
Rolling out 70 mm	25.5*	18.3	22.4*	13.9
Rolling out 38 mm	32.3	34.0	28.5*	23.8
Hydrant: locating and connecting	23.8	22.9	24.9*	19.5
Coupling hoses	39.9*	49.8	36.8	40.9
Drag 70-mm charged hose: flat	16.8	13.7	12.2*	8.5
Drag 38-mm charged hose: flat	27.2	29.5	26.1*	18.8
Drag 38-mm charged hose: stairs	13.6*	6.1	10.4*	3.6
Stairs: PPE, BA, hose	13.7*	6.7	9.9*	4.1
Stairs: PPE, BA, hose, tools	26.3*	2.8	12.0*	3.0
Using 38 mm	18.5	16.0	15.4*	10.9
Using 70 mm	10.5	7.6	5.8*	6.4
Fire attack	15.6	11.5	12.4*	9.3
Ladder use: 4.6 m	22.0*	10.4	20.3*	6.8
Ladder use: 10.5 m: 1 person	15.5*	5.5	11.3*	3.7
Ladder use: 10.5 m: 2 people	16.2*	6.6	11.5*	4.9
Rescue victim: ladder - 2 people	5.1	1.8	4.8*	2.4
Rescue victim: stairs - 2 people	5.7*	1.8	4.0*	2.1
Rescue FF: 1 person	4.0	3.6	3.5	3.2
Rescue victim: 2 people	4.1	2.3	3.4	2.9
Moving victim	8.2*	3.3	5.5*	2.7
Using spreaders and shears	17.3*	4.2	15.3*	5.1
Prolonged static work	11.3*	3.5	7.3*	3.0
Using sledge hammer	12.4*	2.7	6.7*	2.5
Carry: ventilation fan (stairs): 2 people	15.4*	5.2	10.5*	3.4
Carry: Davey pump: two people	8.7	6.0	8.3*	4.0
Pulling down ceiling	11.1*	5.2	8.3*	3.7
Hazmat: walking, manual handling	6.1*	2.3	5.1*	2.7
Tunnel search and rescue	3.8	2.0	2.0	2.3
Bush: walking, manual handling	5.1	3.0	4.0*	2.5
Bush: drag charged hose	10.8	14.2	12.7*	5.6
Bush: digging fire break	5.9	7.1	6.9	5.0

Notes: P-Metro = permanent metropolitan; R-Metro = retained metropolitan; P-Region = permanent regional; R-Region = retained regional. Shading: red > 24, orange: 12-24, white = 6-12, green = < 6. Superscripts denote statistical differences (⋆).

Table 2.10: Task performance durations (minutes) grouped by employment classification.

Task	P-Metro	R-Metro	P-Region	R-Region
Rolling out 70 mm	2.7	1.4	6.1	1.7
Rolling out 38 mm	2.9	1.5	8.3	1.7
Hydrant: locating and connecting	5.7	4.8	10.2	4.3
Coupling hoses	1.9	2.0	6.2	2.3
Drag 70-mm charged hose: flat	7.1	3.8	10.3	4.7
Drag 38-mm charged hose: flat	8.9	5.6	14.2	6.9
Drag 38-mm charged hose: stairs	8.2	4.9	11.4	5.8
Stairs: PPE, BA, hose	9.9	6.7	12.8	7.8
Stairs: PPE, BA, hose, tools	9.6	6.3	15.6	7.6
Using 38 mm	32.3	23.9	31.7*	23.7
Using 70 mm	38.1*	18.6	29.9*	17.4
Fire attack	18.2	17.7	24.4	16.1
Ladder use: 4.6 m	10.5	6.9	13.8	9.7
Ladder use: 10.5 m: 1 person	7.5	5.0	10.3	6.5
Ladder use: 10.5 m: 2 people	7.1	5.1	9.4	6.4
Rescue victim: ladder - 2 people	8.6	9.6	13.2	10.5
Rescue victim: stairs - 2 people	9.3	12.2	12.4	10.1
Rescue FF: 1 person	8.4	10.1	12.2	12.4
Rescue victim: 2 people	8.6	9.7	11.9	12.3
Moving victim	10.7	13.8	16.0	10.0
Using spreaders and shears	19.5	13.6	24.0	19.2
Prolonged static work	23.3	17.9	26.0	20.1
Using sledge hammer	3.2	3.7	6.9	5.1
Carry: ventilation fan (stairs): 2 people	6.6	6.1	10.3	6.8
Carry: Davey pump: two people	7.4	8.0	11.3	8.3
Pulling down ceiling	13.5	9.1	18.0	12.3
Hazmat: walking, manual handling	29.9	18.1	31.6*	20.2
Tunnel search and rescue	28.0	12.0	33.2	19.7
Bush: walking, manual handling	34.5	19.4	38.3*	22.5
Bush: drag charged hose	57.7*	20.7	50.3*	24.3
Bush: digging fire break	62.9*	26.0	64.8*	24.3

Notes: P-Metro = permanent metropolitan; R-Metro = retained metropolitan; P-Region = permanent regional; R-Region = retained regional. Shading: red >30, orange: 15-30, white = 5-15, green = <5. Superscripts denote statistical differences (⋆).

superscript "⋆" has been positioned in the column for the permanent firefighters to show that data in the corresponding cell of the adjacent column (retained firefighters) differ significantly ($p < 0.05$). The nature of each fire-fighting situation is heavily dependant on the incident. Differences including the number of people present, atmospheric temperatures, state of the fire and prevalence of noxious gases ensures no two situations are ever exactly the same. Thus, it could be argued that durations of a typical incident may vary dependent on the situation. While this to a degree is true, the broad range of responses from all classifications, gender and age, along with the large sample size indicates these responses were a valid representation of the average duration of each trade task. The longest tasks were the bush-fire related tasks. These included digging a fire break in bushland (mean 56.33 min, SD 64.80) and dragging a 38-mm hose on uneven terrain through bushland (mean 49.01 min, SD 63.74). The shortest task reported was the coupling un uncoupling of hoses (mean 2.51 min, SD 13.72), followed by rolling out 70-mm hose (mean 2.74 min, SD 13.90). For the majority of tasks, permanent firefighters reported longer average durations than retained firefighters.

Question 10[1] from the employee survey was included as both a cross-check and calibration question. Firefighters were asked to identify which tasks they felt their performance was limited due to their physical capacity (*e.g.* endurance, strength). Table 2.11 (all respondents) summarises these answers, where the top ten tasks that the respondents felt limited by physical capacity are listed. Also presented are the corresponding data for the ratings of physical effort required to perform each of these tasks (top ten in descending order). Seven common fire-fighting tasks in the top ten fit both these criteria. This correspondence is taken as a broad validation of the ratings of physical effort.

Table 2.12 summarises answers to Question 10 from the employee survey (tasks performance limited by physical capacity) by separating the responses of those firefighters who are >50 years of age. Given the prevalence of older individuals within Fire & Rescue

[1] Question 10: Have you ever found that your ability to perform one of the tasks listed was limited by some aspect of your physical capacity (*e.g.* strength, endurance or cardiovascular fitness)?

Table 2.11: Tasks respondents reported as being limited by their physical capacity (left two columns) and the physical effort (right two columns) required to perform these tasks. Data are firefighter responses regarding absolute counts (limitations) and effort ratings (scale: 1-5). Tasks that fit both these criteria are highlighted in bold.

Physical Capacity- Task	Count	Physical Effort- Task	Rating
Drag 70-mm charged hose: flat	**257**	**Rescue FF: 1 person**	**4.8**
Stairs: PPE, BA, hose, tools	**248**	Rescue victim: 2 people	4.6
Using 70 mm	**248**	**Stairs: PPE, BA, hose**	**4.5**
Stairs: PPE, BA, hose	**244**	**Stairs: PPE, BA, hose, tools**	**4.3**
Bush: drag charged hose	**217**	**Drag 70-mm charged hose: flat**	**4.3**
Coupling hoses	206	**Using 70 mm**	**4.3**
Fire attack	204	Rescue victim: stairs - 2 people	4.2
Drag 38-mm charged: stairs	**201**	Rescue victim: ladder - 2 people	4.2
Rescue FF: 1 person	**198**	**Drag 38-mm charged: stairs**	**4.2**
Hazmat: walking, manual handling	168	**Bush: drag charged hose**	**4.2**

Table 2.12: Task performances limited by firefighter's physical capacity (% affirmative).

Task	Male	Female	> 50 years
Rolling out 70 mm	8.7%	11.8%	6.1%
Rolling out 38 mm	4.3%	2.0%	2.0%
Hydrant: locating and connecting	8.0%	5.9%	3.6%
Coupling hoses	20.6%	19.6%	14.2%
Drag 70-mm charged hose: flat	25.7%	25.5%	21.8%
Drag 38-mm charged hose: flat	8.7%	2.0%	6.6%
Drag 38-mm charged hose: stairs	20.4%	13.7%	13.2%
Stairs: PPE, BA, hose	24.7%	17.6%	19.8%
Stairs: PPE, BA, hose, tools	24.5%	29.4%	24.4%
Using 38 mm	11.3%	7.8%	8.1%
Using 70 mm	25.4%	13.7%	24.4%
Fire attack	21.1%	9.8%	21.3%
Ladder use: 4.6 m	5.8%	2.0%	3.0%
Ladder use: 10.5 m: 1 person	14.9%	17.6%	12.7%
Ladder use: 10.5 m: 2 people	11.8%	5.9%	8.1%
Rescue victim: ladder - 2 people	14.6%	3.9%	12.2%
Rescue victim: stairs - 2 people	15.4%	7.8%	9.6%
Rescue FF: 1 person	20.0%	13.7%	16.8%
Rescue victim: 2 people	16.0%	13.7%	10.2%
Moving victim	12.4%	2.0%	11.2%
Using spreaders and shears	13.5%	13.7%	8.6%
Prolonged static work	8.7%	2.0%	6.6%
Using sledge hammer	10.0%	7.8%	5.6%
Carry: ventilation fan (stairs): 2 people	11.4%	5.9%	9.1%
Carry: Davey pump: two people	9.9%	3.9%	10.2%
Pulling down ceiling	9.2%	9.8%	4.6%
Hazmat: walking, manual handling	17.1%	7.8%	20.8%
Tunnel search and rescue	9.2%	2.0%	8.6%
Bush: walking, manual handling	11.1%	2.0%	8.6%
Bush: drag charged hose	22.0%	15.7%	23.4%
Bush: digging fire break	11.8%	2.0%	9.1%

Notes: Shading: red: 20% or more firefighters found their physical capacity to be a limiting factor when performing this task.

NSW (personal communication, Fire & Rescue NSW), this separation is critical in observing whether a relationship exists among older individuals and their physical capacity/incapacity to complete a task. Cells are shaded red (in rows) to correspond with those tasks in which >20% of the male firefighters found their physical capacity had limited their performance. It should be noted that although this figure was arbitrary, it would support a broad identification of tasks where physical capacity would prove a limitation. Nine tasks were identified. There is good agreement across seven of these, that is >20% of both males and >50 year olds were limited by their physical capacity, with just two (coupling hoses; dragging charged hose up stairs) in which older firefighters felt limited by their physical capacity but not to the same extent as males.

2.3.3 Filtration of trade tasks

Due to the magnitude and inefficiency of observing, quantifying and evaluating the physical and physiological demands of all thirty-one tasks listed in the survey, a manageable list of recommended trade tasks was created for detailed study in Chapter Three of this dissertation. A range of criteria (Section 2.3.3.1- 2.3.3.4) was used to filter this preliminary list down to a manageable size, and these are explained in detail below. Since it would be inefficient to study all tasks, the author explored the possible exclusion of tasks if efficiencies could be gained without compromising the integrity of the process while adopting a decision-analysis approach (Howard, 1966). This type of approach focusses on incorporating and balancing the numerous factors which affect a decision. Therefore, in combination with the survey responses (Tables 2.3-2.12), a filtration mechanism was devised, in collaboration with members of the Research Team (Figure 2.2), and independently applied to each of the four employment classifications.

2.3.3.1 Exclusion criterion one: tasks with sub-threshold physical effort

Tasks with a physical effort less than three (scale: 1-5) reported in the survey were removed from the trade-task list in accordance with this criterion. This threshold was based on the two calibration tasks (rolling out 38-mm hose (mean response: 2.4) and using a 4.6-m ladder to gain access, rescue or complete salvage work (mean response: 3.0)). Thus, a threshold of 3.0 for physical effort was taken for this exclusion criterion. This threshold

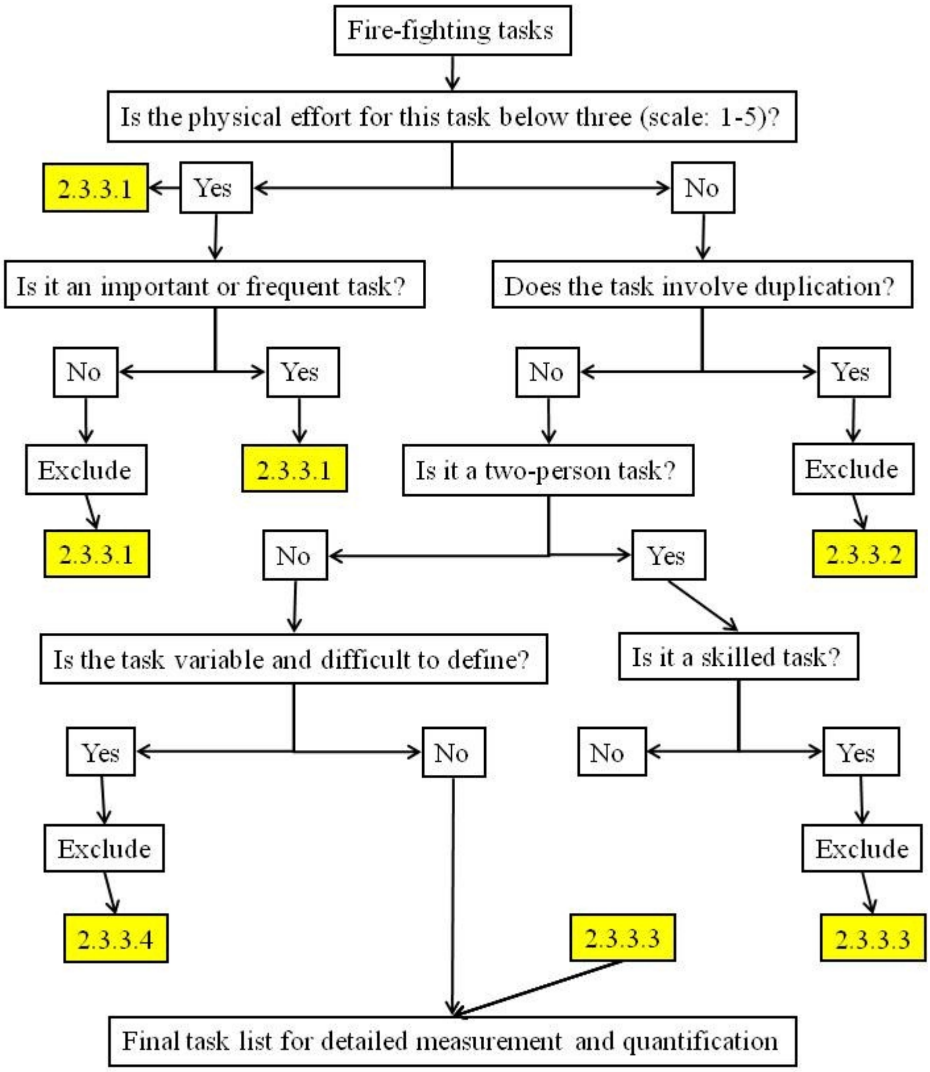

Figure 2.2: A flow chart for determining the final list of trade tasks for detailed evaluation and analysis. The numbered boxes correspond to the task exclusion criteria that relate to the numbered sections within this dissertation. Where numbered sections re-appear more than once (*e.g.* 2.3.3.1 and 2.3.3.3), tasks within these sections are re-considered for inclusion based upon the relevant re-inclusion (cross-check) criteria.

was set under the assumption that tasks with a physical effort less than three would not be useful in the identification of either potentially superior or inferior firefighters. For instance, if a firefighter could perform numerous tasks that were much harder, and of a similar nature to these sub-threshold tasks, then it would be assumed that the firefighter could also perform these less physical trade tasks. Understanding this, such tasks would probably not be included within a pre-employment screening test, at least not as individual test items. These criteria were approved by members of the Management Team.

This exclusion criterion (and those proceeding it; 2.3.3.2-2.3.3.4) may possess limitations, as it is based on a pre-determined threshold for physical effort. For instance, these thresholds are somewhat subjective. However, there has been little previous literature that is both relevant and applicable to this approach. Gledhill and Jamnik (1992b) developed optimum (passable) scores for different fitness components within a physiological screening test for firefighters. They determined these scores by grading scores one standard deviation above the minimum means score for the different fitness components.

Most applicable to the exclusion rationale (2.3.3.1-2.3.3.4) presented in the current research is the work done towards the development of physical employment standards for correctional officers by Jamnik *et al.* (2010). Jamnik *et al.* (2010) applied thresholds for the inclusion of trade tasks within a screening test for importance ($\leq$2 very or critically important), physical demand (effort; $\leq$3 moderately high, high or very high) and frequency ($\leq$3.5 monthly, weekly, or daily). These criteria were established in consultation with experienced personnel (senior correctional officers). This work lends support towards the application of inclusion/exclusion thresholds to determine the essential, physically tasks within the current research. Given the subjective nature of these thresholds, consultation with the subject matter experts from the Management Team was critical in approving these thresholds (Section 2.3.3.4). This is expected, given the ability of these personnel to enhance such processes (Truxillo *et al.,* 2004). It is believed the establishment of the aforementioned, and proceeding, exclusion criteria (2.3.3.1-2.3.3.4) assisted in conducting a thorough and detailed job analysis, an essential component for physiological employment standards to be legally defensible (Constable and Palmer, 2000). Furthermore, the basis for this approach could also improve test efficiency (personal communication, Fire & Rescue NSW). Hence, in accordance with exclusion criterion one, the following tasks were eliminated from each employment category:

- Rolling out 70-mm hose:
    - retained metropolitan
    - permanent regional
    - retained regional.
- Rolling out 38-mm hose *{Note: This item was included as a calibration task}*:
    - permanent metropolitan
    - retained metropolitan
    - permanent regional
    - retained regional.
- Finding hydrant, carrying necessary equipment, getting water to appliance:
    - retained metropolitan
    - retained regional.
- Coupling hoses:
    - permanent metropolitan
    - retained metropolitan
    - permanent regional
    - retained regional.
- 4.6-m ladder use: gaining access, rescue, salvage *{Note: This item was included as a calibration task}*:
    - permanent metropolitan
    - permanent regional.
- Prolonged static work (*e.g.* holding victim's head):
    - permanent metropolitan
    - permanent regional.

Re-inclusion criterion one: tasks with a high frequency, importance or physical limitation

Nevertheless, there were exceptions to this first exclusion criterion. A sub-threshold task was reinstated to the trade-task list if it was performed very frequently (>30 occasions annually: *i.e.* more frequent than the calibration task), if it was more important than the higher of the two calibration tasks (4.1 on scale 1-5), or if it was identified as an activity that was reported by more than 20% of all firefighters to be limited by their physical capabilities (Table 2.12). It is believed these additional analyses would assist in alleviating possible limitations (*e.g.* wrongful exclusion of a task). Tasks retained on these bases were:

- The location and connection of a hydrant:
    - permanent metropolitan: importance criterion (4.5)
    - retained metropolitan: importance criterion (4.5)
    - permanent regional: importance criterion (4.4)
    - retained regional: importance criterion (4.4).
- Coupling hoses:
    - task limited by physical capacity criterion: all classifications
    - permanent metropolitan: frequency criterion (39.9 times *per annum*)
    - retained metropolitan: frequency criterion (49.8 times *per annum*)
    - permanent regional: frequency criterion (36.8 times *per annum*)
    - retained regional: frequency criterion (40.8 times *per annum*).

2.3.3.2 Exclusion criterion two: task duplication

Tasks that required less physical effort when duplicated, or deemed to be sufficiently similar in nature, were removed from the trade task list in accordance with this criterion. This criterion was based on the assumption that duplicating tasks (where two or more tasks were deemed to be sufficiently similar in nature) would be inefficient in compiling the essential trade-task list. Tasks eliminated at this step include the following, and this occurred simultaneously across each of the four employment classifications in cases where duplication was relevant for tasks still within the list:

- Dragging 38-mm charged hose across horizontal surfaces: More physical effort is required to drag a 70-mm charged hose and to drag a 38-mm charged hose up a flight of stairs (Table 2.8).
- Dragging 38-mm charged hose up a stairway: Duplicates stair climbing when wearing the full personal protective ensemble and self-contained breathing

apparatus and dragging charged hose; the latter was rated as more difficult (Table 2.8).

- Moving victims with salvage sheets or Stokes Litter: Across classifications, firefighters rated this task to be less difficult (Table 2.8) and less important (Table 2.7) than a one-person rescue of a firefighter wearing the full personal protective ensemble and breathing apparatus.
- Prolonged static work (*e.g.* holding victim's head): In all employment classifications, firefighters rated this task to be less difficult than using spreaders and shears (Table 2.8):
    - retained metropolitan
    - retained regional.
- 4.6-m ladder use: gaining access, rescue, salvage: In all employment classifications, firefighters rated this task to be less difficult than using a 10.5-m ladder (under running and stabilising; Table 2.8) *{Note: The 4.6-m ladder task was included as a calibration task}*:
    - retained metropolitan
    - retained regional.
- Stair climbing: personal protective equipment, breathing apparatus, charged hose, high-rise pack, tools: For three of the four employment classifications, this task was rated as less difficult than stair climbing when wearing the full personal protective ensemble and breathing apparatus, and dragging a charged hose (Table 2.8).
- Carrying Davey pump: two people: Across all classifications, firefighters rated this task to be less difficult than carrying the ventilation fan (Table 2.8).
- Bush: walking with cordage pack or Stokes Litter: Less effort than dragging a charged hose (bush) on hilly, sloped and uneven surfaces (Table 2.8).

2.3.3.3 Exclusion criterion three: two-person tasks and skill component

The research team sought to eliminate variability by removing, where relevant and practical, tasks that are typically performed by two firefighters and which also have a significant skill component. This variability can arise due to the influence of factors such as skill (technique) on the interaction between the two individuals during the performance of the task. Hence, consideration must be placed on the factor of skill included in physical screening tests (Equal Employment Opportunity, 1978; Constable and Palmer, 2000). As such, within-task performance, this variability can reduce measurement precision. Furthermore, since the eventual aim is to develop screening tests for firefighters (tests performed individually) it seems impractical to quantify tasks that involve two or more individuals (personal communication, Fire & Rescue NSW). While there is no doubt skill is included in almost all physical tasks, the degree to which the skill dictates the completion of the task must be carefully managed. For instance, it is known physiological changes can occur with the acquisition of motor skills (Kleim, *et al.*, 1996; Nudo *et al.*, 1996; Vandenberg *et al.,* 2002). Given skill is a critical part of firefighter training (*e.g.* operating heavy machinery) and can be taught proceeding recruitment, physiological employment screening tests should primarily target key physiological attributes so employees are measured on physical performance (Constable and Palmer, 2000).

The following two-person tasks were considered to have a significant skill component, and were thus eliminated from all classifications:

- Rescue victim while wearing personal protective equipment and breathing apparatus: two people: In all employment classifications, firefighters rated this task to be less difficult (Table 2.8) and less important (Table 2.7) than a one-person rescue of a firefighter wearing the full personal protective ensemble and breathing apparatus.
- Rescue victim via ladder: two people: Eliminated due to skill required, effort of second person and difficulty of incorporating this task into a single-person screening test. This task was considered to be potentially more dangerous for use in a screening test.
- Rescue victim via stairs: two people: Eliminated due to skill required, effort of second person and difficulty of incorporating this task into a single-person screening test. This task was also considered to be slightly more dangerous.
- 10.5-m ladder use: two-person removal and replacement: Task was rated less

difficult than using a 10.5-m ladder (under running and stabilising) by all classifications (Table 2.8).

However, if a two-person task was unskilled and individual contributions could easily be measured, then that task was retained. One task was retained across all classifications:

- Carrying ventilation fan up stairs: two people: This task was universally rated as being more difficult than carrying the Davey pump (Table 2.8), and it is easy to determine the load distribution for this task between two individuals. Thus, one could imagine that performance on a single-handed carry task could provide an adequate prediction of performance for this task.

One two-person task presented difficulty:

- Prolonged use of charged hose: 70 mm (two people): Even though this task is a two-person activity, it was universally rated as requiring more physical effort that using a 38-mm charged hose (Table 2.8). It was recommended that the possible inclusion of this task within the final list of trade tasks be discussed and determined by the Project Management Team.

2.3.3.4 Exclusion criterion four: task is variable and difficult to define

Three tasks were difficult in define, due both to the nature of each task and the widely variable duration reported for each within the survey. These characteristics would make it very hard to narrow these tasks down into a discrete and reproducible task (with clear start and end points) that could be simulated, evaluated and subsequently used within a screening test. Whilst this may be so for many activities of fire fighting, it is particularly pertinent to the tasks below. Indeed, this limitation would render the inclusion of such items within screening tests as questionable. That is, one may argue, that since the ends points were hard to define, task performance thresholds would be equally hard to define.

On this basis, the following tasks were eliminated from each employment classification:

- Tunnel search and rescue:
    - permanent metropolitan: duration 28.0 min (SD 37.7)

    - retained metropolitan: duration 12.0 min (SD 10.7)
    - permanent regional: duration 33.2 min (SD 46.4)
    - retained regional: duration 19.7 min (SD 13.9).
    - In addition, this activity involved duplication with several other tasks, and all classifications rated it as being less difficult than (Table 2.8):
        - prolonged crawling, kneeling, crouching, squatting: fire attack
        - rescue firefighter wearing protective equipment and breathing apparatus (one person)
        - dragging a 70-mm charged hose
        - dragging a charged hose (bush) on hilly, sloped and uneven surfaces.
- Pulling down ceilings using ceiling hook:
    - permanent metropolitan: duration 13.5 min (SD 17.0)
    - retained metropolitan: duration 9.1 min (SD 8.4)
    - permanent regional: duration 18.0 min (SD 30.2)
    - retained regional: duration 12.3 min (SD 8.6).
- Bush: digging fire break (McLeod Tool):
    - permanent metropolitan: duration 62.9 min (SD 67.9)
    - retained metropolitan: duration 26.0 min (SD 22.4)
    - permanent regional: duration 64.8 min (SD 75.5)
    - retained regional: duration 24.3 min (SD 16.3).

Tasks inclusion cross-check procedures

Pre-defined thresholds and criteria can introduce variation into the experimental observations. Indeed, there is previous evidence of this occurring in large scale health assessments (McColl, *et al.,* 2001; Cassidy *et al.,* 2004). Thus, in an attempt to not exclude tasks from the final trade-task list inappropriately, two cross-checking methods were instated. The first step was focussed upon trade task importance, difficulty, and task performance frequency, duration and work volume[2]. Within Tables 2.7-2.10, these critical tasks were identified (red shaded cells). Thus, this analysis involved cross checking to see that these tasks had not been eliminated from the final task list without appropriate justification. Only two tasks from those highlighted were not included at the end of this process, and these, along with the reasons for their recommended exclusion, are provided below:

- Bush: walking with cordage pack or Stokes Litter: Excluded from all classifications due to task duplication and requiring less effort than dragging a charged hose (bush) on hilly, sloped and uneven surfaces.
- Bush: digging fire break (McLeod Tool): Excluded from all classifications due to the task being both widely variable in duration and difficult to define.

It should be noted that although rolling out 70-mm hose was also recommended for exclusion (due to physical effort being less than the threshold of the more difficult calibration task in three employment classifications), this task was retained at the request of the Management Team due to its criticality.

The second step emphasised trade tasks that were identified as being limited by the capacity of each respondent. The threshold for this check was that at least 20% of all firefighters found the task to be limited by their physical capabilities (Table 2.12 (red cells)). If a task was not > 20% for all firefighters then the task was not considered for the next stage in this process. Therefore, this stage also involved cross checking to ensure that such tasks had not been eliminated without an appropriate justification. Only one task from those highlighted was not included at the end of this process:

- Stair climbing: personal protective equipment, breathing apparatus, charged hose, high-rise pack, tools: For three of the four employment classifications, this task was rated as less difficult than stair climbing when wearing the full personal protective ensemble and breathing apparatus, and dragging a charged hose (Table 2.8).

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[2] Work volume (minutes) equals the product of task frequency and task duration.

Since this two-level, cross-checking procedure failed to identify any tasks that had been inappropriately eliminated, then it was concluded that this filtration mechanism was valid. These analyses resulted in the identification of fifteen tasks across the four employment classifications. The author (in collaboration with the Research Team) believes this was a valid and representative subset of physically demanding activities associated with fire fighting, as performed in regional and metropolitan NSW. The arrival of the list at fifteen items ensured this was a manageable list of trade tasks that could be further examined in proceeding studies within this dissertation. Following the approval of members of the Management Team, this process was conducted in Chapters Three and Four.

This final trade-task list was derived by computing the subjective stress (task difficulty rating multiplied by task performance frequency) imposed on firefighters when performing each task. This analysis was conducted to further validate the current methods chosen to identify the essential task. These data permitted a simple ranking of all tasks with respect to imposed stress, and the ranks for the fifteen tasks identified from these procedures are presented in Table 2.13. This ranking system does not capture absolute differences between scores. Conclusions drawn from this data include:

- Whilst it is widely recognised that surveys can result in the artificial inflation of the absolute values for subjective ratings (Aadahl and Jørgensen, 2003; Rzewnicki *et al.*, 2003), the uniformity of the current responses indicates that the relative position of each task within this ranking is valid.
- The current methods, in combination with the survey sample size, have lent support towards the valid identification of the essential tasks for the next phase of this research (Chapter Three).
- The tasks identified represent the appropriate fire-fighting tasks for each of the employment classifications of firefighters.
- Across the four employment classifications, the tasks identified included at least one of the top three most stressful tasks, and at least five of the ten most stressful tasks.
- The current methods lend support to the valid identification of both

Table 2.13: Subjective stress ranking within employment classifications for the fifteen tasks identified. Ranks are from 1-30 (1=most stressful). Tasks that were in the top ten for subjective stress are shaded.

Task	P-Metro	R-Metro	P-Region	R-Region
Rolling out uncharged hose lines: 70 mm	28	29	30	29
Hydrant: locating and connecting	26	26	25	27
Coupling and uncoupling hoses	30	28	29	28
Drag 70-mm charged hose: horizontal	20	25	21	25
Stair climb with PPE, BA, hose	11	16	15	17
Prolonged use of 38-mm hose	6	2	7	3
Prolonged use of charged hose: 70 mm (two people)	3	4	6	7
Fire attack: prolonged crawl, kneel, crouch, squat	9	7	8	10
Ladder use (10.5 m): 1-person, under run	22	23	22	21
Rescue FF with PPE, BA: 1 person	14	13	13	11
Using spreaders and shears	8	11	9	8
Using sledge hammer to gain entry	27	27	27	26
Carry: ventilation fan (up stairs): 2 people	25	19	24	23
Hazmat: walking, manual handling (encapsulated)	4	5	3	4
Bush: drag charged hose (hilly, sloped, uneven)	1	3	2	1

Notes: P-Metro = permanent metropolitan; R-Metro = retained metropolitan; P-Region = permanent regional; R-Region = retained regional. Shading: red: task ranked in the top ten for subjective stress.

high- and low-stress tasks.

- Within each employment classification, the tasks identified represent a broad range of subjective stress.

Given the legal ramifications of discriminatory standard development and implementation (Constable and Palmer, 2000; Barr and Flannery versus the Treasury Board of the Department of National Defence, 2006; Docherty *et al.*, 2007), selection procedures must ensure that screening tests are valid representations of critical duties derived from an extensive job analysis (Payne and Harvey, 2010). From all perspectives (age, gender, employment classification, experience level), it is believed this survey is an appropriate instrument in developing legally defensible physiological employment standards as it entails an adequate representation across the fire-fighting organisation (Fire & Rescue NSW).

2.4 DISCUSSION

In this investigation a trade-task list entailing fifteen essential and physically demanding fire-fighting tasks were established. These tasks, to the author's knowledge, have not previously been identified. This list was constructed from information derived from focus groups, an employee survey and a filtration process determining task inclusion and exclusion criteria. This discussion will focus on why the processes employed lend support to the valid representation of essential and physically demanding activities associated with fire fighting, as performed in regional and metropolitan NSW. However, whilst discussing the relevance of these findings to the demands of fire fighting within NSW and their relationship within the literature, one must also recognise the limitations associated with the focus groups, employee survey and filtration processes employed in this investigation. These points will be made, where relevant, throughout the text. This investigation allows for the evaluation and quantification of each of the fifteen essential and physically demanding trade tasks to take place (Chapter Three).

2.4.1 The identification of essential and physically demanding trade tasks

Previous authors have shown that firefighters themselves have reported their occupation encompasses tasks that are considered essential and physically demanding, through task analyses and employee questionnaires (Gledhill and Jamnik, 1992a; Phillips, *et al.,* 2012). Furthermore, the identification of these tasks can be supported by the collection of physiological data, which quantifies these tasks and displays considerable physiological strain (Gledhill and Jamnik, 1992a). This quantification process entails measurement of cardiorespiratory variables through open-circuit, expired gas analysis and ventilation systems, to ascertain direct measures of oxygen consumption, or utilising heart rate to give estimations of the energetic requirements of fire-fighting trade tasks (Smolander *et al.*, 1985; Sothmann *et al.*, 1991; Bilzon *et al.*, 2001a). The identification of the fifteen essential and physically demanding fire-fighting tasks in this investigation included manual handling tasks, the use of hoses, stair climbing, ladder use, and rescue, hazmat and bush related activities (Table 2.14). The following text will provide statistical, numerical and physiological evidence to support this list being a valid representation of the physically demanding activities associated with fire fighting, as performed within NSW.

For instance, the most important (mean 4.86, SD 0.50) and difficult (mean 4.78, SD 0.58) task reported in the employee survey from this investigation was the firefighter rescue. The high rating of task difficulty for the firefighter rescue may be attributable to the strenuous nature of the task. Indeed, this would be consistent with physiological data indicating rescue activities as some of the most physically demanding fire-fighting tasks (Romet and Frim, 1987; von Heimburg *et al.*, 2006). For instance, von Heimburg and colleagues (2006) reported peak oxygen uptake values of 3.7 $L.min^{-1}$; SD 0.5 (mean 84% of subjects maximal oxygen consumption) for firefighters completing a simulated firefighter rescue. Furthermore, Lusa *et al.* (1993) reported firefighters can perform these rescues in the presence of external stressors, such as heat (119°C; SD 12°C) and smoke, characteristics which would further indicate that performing a firefighter rescue is physiologically extremely demanding.

Moreover, the presence of the large external load being rescued (*i.e.* a firefighter dressed in full personal protective clothing) may inherently make the task more difficult. Indeed, under the influence of external loading (for instance up to 70% of lean body mass; Beekley *et al.*, 2007), metabolic demand will increase (Cavagna *et al.*, 1963; Beekley *et al.*, 2007).

This loading will cause increases in various cardiorespiratory variables (Queseda *et al.,* 2000), such as significant increases in heart rate and ventilation, whilst oxygen consumption can approach maximal levels (mean 91% of subjects maximal oxygen consumption; Beekley *et al.*, 2007). When loaded tasks are performed in ambient conditions, the high physiological demand is most likely attributable to the large external load placing an increasing strain on the activation of the working musculature (Soule *et al.*, 1969; Knapik *et al.*, 1996).

However, subjective stress ratings for the firefighter rescue are low (mean 7.0; Table 2.13). The firefighter rescue was reported as one of the least frequently performed tasks (mean 1.46, SD 4.82, times per annum) in the employee survey. The average volume (the product of task frequency and task duration) was reported at 13.5. Neither of these values were in the top ten for these respective ratings, for example subjective stress (Table 2.13). Tasks with high performance frequency and importance predominately indicate high criticality (Taylor and Groeller, 2003). Therefore, one could argue this task should not be included on a final trade-task list, as it is very rare that firefighters will perform this task. However, firefighters in the focus groups indicated they would change their behaviour if they did not think their firefighter partner could drag them out as required. Thus, despite the low performance frequency and associated product ratings, the absolute criticality (lifesaving nature) of the task lends support for the valid inclusion of the firefighter rescue in the final trade-task list, based on its high ratings of importance and difficulty. Furthermore, every firefighter is expected to have the physical capacity to drag a fellow firefighter to safety. Hence, subjective stress ratings must be carefully managed when filtering trade tasks, as to not wrongly exclude critical tasks from the final trade-task list.

The motor-vehicle rescue (the use of heavy equipment, such as the spreaders= 19.5 kg), carrying a ventilation fan (35 kg) and the use of a sledge axe to gain entry were ranked in the top-ten for subjective stress in three or more employment classifications (Table 2.13) in the employee survey. Physiological evidence from previous investigations support the inclusion of manual-handling tasks in the final trade-task list, as these tasks encompass a high physiological demand (Lemon and Hermiston, 1977a and b; O'Connell *et al.*, 1986;

Gledhill and Jamnik, 1992b; Bilzon *et al*, 2001a and b). Gledhill and Jamnik (1992a) reported high heart rates at 164 beats.min^{-1} (SEM 4) for forcible entry, a similar task to the sledge axe task reported as essential and physically demanding in the current study (Table 2.13). Furthermore, Bilzon *et al.* (2001a) quantified the metabolic demand associated with the carriage of an extinguisher, during a simulated shipboard fire-fighting task, as 39 mL.kg.min^{-1} (SD 4; mean 79% of subjects maximal oxygen consumption). In addition, the hazmat task in the current study was characterised by focus groups as a task involving repeated unilateral carriage when removing hazardous materials from an incident.

Moreover, the physical effort associated with the hazmat task was reported highly (4 or greater out of scale 1 to 5) by all employment classifications in the employee survey. Furthermore, the carriage of equipment from an incident has been found to elicit high heart rates (mean 172 beats.min^{-1}, SEM 4; Gledhill and Jamnik, 1992a), supporting respondents indication of the strenuous nature of the manual-handling tasks such as the 10.5 m ladder, locating and connecting a hydrant, stair climb with a ventilation fan and the hazmat task. The high physiological strain associated with these manual-handling tasks lends support to their inclusion on the final trade-task list, especially since physical employment standard development must reflect the most physically demanding tasks of the occupation (Jamnik, 2010a).

Six of the fifteen essential and physically demanding fire-fighting tasks involved the use of a charged hose (Table 2.13). The frequency of hose use is similar to the high prevalence of hose-related tasks in previous investigations, with eight in Victorian rural fire fighting (Phillips *et al.*, 2012) and four reported by Canadian fire-fighting incumbents (Gledhill and Jamnik, 1992a). This suggests that fire suppression, where the use of hoses is essential, is prominent within fire-fighting tasks performed in NSW. Moreover, physiological data within the previous literature indicating the strenuous physical demands of hose work support the inclusion of these tasks in the final trade-task list (Drag 70-mm charged hose, stair climb with charged 38-mm hose, fire attack and bush hose drag, prolonged use of 38- and 70-mm hoses).

For example, the lateral repositioning of a hose has been shown to elicit a mean oxygen consumption of 31.7 $mL.kg^{-1}.min^{-1}$ (SEM 2.8; approximately 70% of maximal oxygen consumption; Gledhill and Jamnik, 1992a), whilst firefighters advancing hoses on Navy vessels elicit 38 $mL.kg^{-1}.min^{-1}$ (mean 77% of subjects maximal oxygen consumption; Bilzon *et al.*, 2001). The mass of the hose will increase with the diameter of the hose, indicating 70-mm hose tasks in the current study would presumably be more physically demanding, as increased external loading will drive increases in cardiorespiratory variables (Queseda *et al.,* 2000; Beekley *et al.*, 2007). However, since 70-mm hose tasks are performed in pairs and 38-mm hose tasks are individual, further research is required to determine which activity is more physically demanding. Having numerous hose tasks in a proposed screening test is impractical given the prolonged duration of such tasks (*e.g.* mean duration 38-mm hose 30.0 min; Table 2.10; personal communication Fire & Rescue NSW). Thus, determining the most demanding hose tasks will assist in developing efficient screening tests.

There is good evidence to suggest stair-climbing tasks are physiologically demanding. For example, the physiological demand of stair climbing has also previously been quantified, with groups of firefighters performing various simulated fire-fighting tasks, of which the tower stair-climbing activity elicited the highest mean oxygen consumption of any task, ascertaining 3.56 $L.min^{-1}$ (SD 0.27; Holmér and Gavhed, *et al.*, 2007). Moreover, Milligan *et al* (2010) evaluated unilateral load carriage (20 kg) up a flight of 15 steps for three minutes, reporting a mean relative oxygen consumption of 33.4 $mL.kg^{-1}.min^{-1}$. This data proves the physiological demand associated with loaded stair climbing, providing further evidence the employee survey was an appropriate instrument in identifying the essential, physically demanding tasks of fire fighting. Indeed, this was the purpose of this investigation. Thus, the author believes this assists in developing legally defensible standards, due the survey's involvement in ensuring selection procedures entail tasks that represent the most critical occupational duties (Payne and Harvey, 2010). Furthermore, the number of stairs climbed has been shown to correlate well ($r=0.71$) with peak oxygen consumption (Pollock *et al.*, 1993).

However, in the current study stair climbing was not considered equally demanding across NSW. Metropolitan employees reported significantly greater task importance for stair-climbing tasks than their regional counterparts in the employee survey (Table 2.7). This may be a result of the greater number of high-rise structures in metropolitan areas compared to regional areas. Indeed, the central business district of Sydney entails at least 67 high rise structures, with the tallest buildings ranging from 88-243 m and 19-73 storeys (CTBUH Tall Buildings Database, 2012). Moreover, firefighters from metropolitan stations stated they would regularly encounter buildings of eight storeys or more (personal communication, focus groups). In comparison, firefighters from regional retained stations indicated they rarely encounter buildings higher than two storeys. Thus, it is understandable why metropolitan firefighters placed a greater numerical emphasis on the importance of stair-climbing tasks (Table 2.7). Since metropolitan firefighters report to climb higher structures (personal communication, focus groups), they would then theoretically elicit a higher metabolic and physiological cost than retained employees during stair-climbing activities.

Furthermore, it is important to consider that regional firefighters will be expected to fight a greater number of bush fires than their metropolitan counterparts, particularly in the summer months (personal communication, Fire & Rescue NSW). Whilst all firefighters are expected to perform under such conditions, regional firefighters will typically be exposed to these environmental conditions more regularly. Thus, regional respondents perception of the physiological strain endured when performing a bush fire-fighting task could be different to their metropolitan counterparts. This would presumably affect perceptions of task-performance difficulty and frequency. In this investigation permanent regional employees reported to attend bush dragging hose incidents more frequently than their retained counterparts. Thus, employment classification could effect perceived task ratings. However, this may also be a reflection of the greater number of incidents permanent employees attend due to the full-time nature of their work. Regardless, every firefighter is expected to carry out any role that is assigned to them at a fire suppression (personal communication; feedback from focus groups). Thus, expectations of all firefighters are equal. Therefore, the inclusion of stair-climbing tasks in the final trade-task list, relevant across all employment classifications, is necessary.

In contrast with stair-climbing activities, the relative mean oxygen uptake associated with ladder use do not reach 20 $mL.kg^{-1}.min^{-1}$ in three of the tasks (Gledhill and Jamnik, 1992a). However, in the current study one ladder use task was included in the final trade-task list as essential and physically demanding (10.5-m ladder use), though this encompassed two aspects of Gledhill and Jamnik's (1992a) work (the raising and aerial climb of the ladder). Gledhill and Jamnik's findings suggest these ladder tasks will not be overly strenuous, and thus possibly warrant an exclusion from the final trade-task list of fifteen essential and physically demanding fire-fighting tasks. However, the high ratings of importance for 10.5-m ladder under run by permanent employees (4.2 and 4.0; Table 2.7) and the heavy load of the 10.5-m ladder (49.5 kg), do not support this proposition. Indeed, they warrant the inclusion of a ladder task at this stage of this project.

The bush fire incident (hose drag over uneven terrain) was included in the final trade-task list of fifteen essential and physically demanding fire-fighting tasks. This was a predictable outcome given the strenuous nature of bushland fire fighting (Brotherhood *et al.,* 1997, Budd *et al.*, 1997a and b; Budd, 2001). For example, Brotherhood *et al.* (1997) evaluated the responses of four crews of firefighters building fire lines (breaks) in the Australian bush to simulate a typical bush fire suppression. Heart rate and oxygen consumption increased linearly with productivity up to 50 rakes a minute for seven minutes, whilst pulmonary ventilation increased exponentially at these higher work rates. In the employee survey administered in the current investigation, digging a fire-break in the bush was reported as the most stressful (the product of difficulty and frequency) trade task, primarily due to its long duration (mean 56.70 min, SD 64.80). This is consistent with previous work, as energy expenditure can increase above 500 W (approximately 45% maximal oxygen consumption; Budd *et al.*, 1997a) in fire-fighting activities of a prolonged duration, such as raking during experimental fire suppression (Budd, 2001). Thus, to a degree, the combination of the subjective stress ratings used in this investigation and physiological data recorded in previous studies lend support to the valid identification of physiologically demanding bush-related tasks.

Given the prolonged duration of these tasks and that a derivative of subjective stress is also frequency, it is also important to consider the variability in duration and frequency ratings. Analysis of both the paper surveys and online surveys revealed a variability of these ratings for certain tasks. For instance, the average reported task duration of certain trade tasks were quite variable, for example the bush walk and carry (mean: 33.1 min, SD 37.4 min), ceiling hook (13.5 min, SD 17.5), tunnel search and rescue (27.3 min, SD 36.4 min), digging a fire break (56.2 min, SD 64.8) and hazmat (27.9 min, SD 38.6 min) tasks. Indeed, three of these tasks were excluded: the tunnel search and rescue, ceiling hook and digging a fire break in bushland (section 2.3.3.4). Furthermore, the duration of the bush walk and carry and dragging a charged hose through bush (uneven terrain) were significantly different between both permanent metropolitan and retained metropolitan, and permanent regional and retained regional employees (Table 2.10).

These variable durations make it very hard to narrow these tasks down into a discrete and reproducible task (with clear start and end points) that could be simulated, evaluated and subsequently used within a screening test. Tasks considered too impractical to administer were nominated for exclusion as part of the final filtration process within this investigation. Three tasks were excluded on this basis: the tunnel search and rescue, ceiling hook and digging a fire break in bushland (Section 2.3.3.4). This variability is predictable since these tasks, more so than others in the consolidated list, were reported with the focus groups as incident dependant. The variability in responses could lend support to the known exaggeration and variability of self-reported physical activity (Sims *et al.,* 1999, Rzewnicki *et al.,* 2003). For instance, Rzewnicki and colleagues (2003) performed a cross-sectional study incorporating two different physical activity surveys (International Physical Activity Questionnaire and a modified version) on fifty previously familiarised adults. They found seventy-five percent of the adults reported less physical activity with the modified procedure than the International Physical Activity Questionnaire. Thus, some surveys can be unreliable predictors of physical activity characteristics. However, the survey employed in this study did not undergo a validation process, a possible limitation (Leon *et al.,* 1977), and it was therefore important to establish filtration measures within this investigation, without compromising the integrity of the exclusion process.

In addition, over estimations were further evident when examining paper based and online survey responses. The overestimation may be explained by the format given to the questions. In paper based surveys there was no limit expressed for both frequency and duration questions (open-point scales). For example, when the respondent was asked to indicate how frequently they performed a certain task, they would manually enter the numerical data (*e.g.* 600 times per annum). In comparison, the online survey featured a scroll down list of options, whereby a limit was determined for each variable (*e.g.* 300 or more times per annum; closed point scale). Thus, the means originally reported in the paper surveys for frequency and duration were prone to exaggeration. This may also be a function of the fire-fighting experience of the respondents. Indeed, experienced responders have been found to exaggerate the frequency of demanding tasks more so than less experienced respondents (Landy and Vasey, 1991).

Furthermore, previous research suggests that using an open-point scale can leave the respondent exposed and prone to exaggerate the duration of physical activities (Baty, *et al.*, 1986; Pope *et al.,* 1998). Moreover, Baty and associates (1986) reported significant differences in reported durations of physical activities and actual observed durations. These differences in Baty's study were attributed to the difficulty for the respondents in estimating time periods when recalling such activities performed on previous days or weeks. Comparatively, closed-point scales show good agreement between estimated and actual work time (Wiktorin *et al.*, 1993). Despite the positive agreement between estimated and actual work time found by Wiktorin and associates (1993), the nature of the closed point scales used in Wiktorin's study (based on a proportion of work shift *e.g.* three quarters of work time) were too vague for use in this study. To adequately progress to the next phase of this project (Chapter Three), the durations in the online employee survey were closed point, but were required to be very precise (one minute to hours). This enhanced both the appropriateness of the survey instrument, and the process of developing legally defensible standards (Table 1.1).

Unfortunately, statistically significant differences across different experience levels were not analysed in this study. However, numerical inferences can be made, though not statistically significant, on the function of the fire-fighting experience of the respondents. For instance, the majority of experienced firefighters encompass the permanent: metropolitan and retained regional (11.1 y and 8.8 y respectively; Table 2.4) employment classifications. Overall, permanent: metropolitan firefighters ranked the frequency of the majority of tasks numerically greater than other employment classifications. This could be attributed to permanent employees possessing greater experience by attending more incidents (full-time employees). These possible issues in employee surveys lead some authors to recommend physically demanding tasks be further visually observed, to ascertain accurate evaluations of task duration and frequency (Hughes *et al.,* 1989).

However, the observation of these tasks in real-time emergencies is impractical, highly variable and incident dependant (personal communication, Fire & Rescue NSW). Alternative methods must thus be utilised to alleviate these over-estimation problems in this investigation. Therefore, data from participants more than two standard deviations above the mean were removed. Removing these data, such as the exclusion of inconsistent and careless respondents, will benefit rating systems and enhance test reliability (Wilson *et al.*, 1990). This exclusion process was critical for all variables since task intensity (physical effort) can more likely be overestimated than task duration (Duncan *et al.,* 2001).

When constructing this final trade-task list, it was important to consider that the ultimate aim of this project was to develop screening test recommendations for use on individuals. Thus, tasks involving two individuals were less than ideal for evaluating individual performance, especially since screening individuals is more reliable than two person or group testing. For instance, discrepancies exist amongst evaluations of isometric and isokinetic lifting strength for groups of both men and women (Karwowski and Mital, 1986; Karwowski and Pongpatanasuegsa, 1988), with team lifting strength found to be less than the sum of individual lifting strength (Karwowski and Mital, 1986). Whilst some two-person tasks may be reported as important and difficult (*e.g.* two-person rescue of a victim via a ladder: importance 4.33, SD 1.02; and difficulty 4.22, SD 0.91), such tasks are difficult to replicate in providing a reliable measure of individual performance and were subsequently excluded (section 2.3.3.3). They also present an increased injury risk when untrained people are required to perform the task. Indeed, safety is of the foremost concern. Given the high reward for passing a screening test (*e.g.* employment) there in an increased likelihood of injury for highly motivated participants (Ayoub, 1982), especially if these tests include heavy manual-handling tasks (Snook *et al.*, 1978).

In addition, skill would presumably have the capacity to affect muscular movements, for instance those present and advantageous to functional tasks. Thus, the factor of skill included in physical screening tests must be carefully considered (Equal Employment Opportunity, 1978; Constable and Palmer, 2000). While there is no doubt skill is included in almost all physical tasks, the degree to which the skill dictates the completion of the task must be carefully managed. Indeed, there is strong evidence showing associations with motor skill acquisition and physiological changes in mammals (Kleim, *et al.*, 1996; Nudo *et al.*, 1996; Vandenberg *et al.*, 2002). Thus, if a firefighter is skilled at performing a task, there exists the possibility for efficient individuals to set an unrealistic physical performance standard, one that is utilised for setting criterion measures in the development of screening tests.

It is also imperative to include those from above and below a pre-determined threshold for acceptable job performance when developing screening tests (Payne and Harvey, 2010). If a test is established without this premise, the threshold is most likely not a true reflection of the requirements of the task and is thus open to legal challenges (Constable and Palmer, 2000). Thus, a threshold will maximise true acceptances and true rejections and minimise false acceptances and false rejections. This will identify those most likely to undertake fire-fighting tasks in a safe and productive manner, and whom are well suited to coping with physiological strain.

The uniformity of information derived from focus groups and the employee survey responses across employment classifications lend support to the valid position of each task within this ranking (Table 2.13). The current methods have led to the identification of both high- and low-stress tasks and add further support to the use of the current methods, in combination with the survey sample size, lending support towards a valid identification of the essential, critical and physically demanding tasks of fire fighting as performed within NSW. This is critical for the next phase of this research (Chapter Three).

2.4.2 Considerations of survey design

It is widely recognised that surveys can result in the artificial inflation of the absolute values for subjective ratings (Aadahl and Jørgensen, 2003; Rzewnicki *et al.*, 2003). For instance, Aadahl and Jørgensen (2003) developed and validated a physical activity scale to assess physical activity across diary entries, interviews and an accelerometer using 2500 randomly selected Danish men and women between the age of 20 and 60. The physical activity scale was found to overestimate activity levels when compared with the self-reported diary method and this overestimation was even more pronounced in high-intensity activities. It is thus a possibility firefighters may be prone to exaggerating their survey responses, as at times fire fighting is comprised of physically demanding high-intensity trade tasks (Davis *et al.*, 1982; Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001a; Barr *et al.,* 2010). However, the uniformity in reported durations across all four employment classifications for the majority of trade tasks (few significant differences; Table 2.10) indicates that the relative position of each task within this ranking system is valid even if not representing a final trade task list.

Permanent metropolitan employees reported the greatest number of responses (575) of all employees. The high response of permanent firefighters may be attributable to the nature of their work. Permanent employees are present at the fire station for four consecutive days, before having four days off. Retained employees' work patterns are more sporadic, being called into the fire station only when an incident occurs. For instance, sometimes retained firefighters will not attend an incident in over a month. Without regular attendance in the workplace, retained employees may be less likely to access their electronic mail accounts, and thus paper surveys were delivered to these employees. Herein lies the likely reason for the large response rate of permanent employees of online surveys. Moreover, retained employees comprised 98% of the total respondents for the paper survey. Therefore, the increased response of permanent metropolitan employees is consistent with findings within the literature, which indicates significantly greater responses for online surveys compared to paper surveys (Lonsdale *et al.*, 2006).

Given the legal ramifications of discriminatory standard development and implementation (Barr and Flannery versus the Treasury Board of the Department of National Defence, 2006; Docherty *et al.*, 2007), the process leading to the establishment of selection procedures must ensure there is an adequate representation of subgroups, such as age and gender (Anti-Discrimination Act, 1977; Constable and Palmer, 2000; Docherty *et al.*, 2007; Payne and Harvey, 2010). The female representation within the employee survey was slightly greater than the full time female representation of the Fire & Rescue NSW workforce (3.2%; NSW Fire Brigades, 2010), with women comprising 5.2% of the total survey responses. Similarly, there was a broad distribution of ages amongst most employment classifications and both genders (Table 2.3-2.4; Table 2.6). For example, the ages of respondents ranged from 18-74 years (mean age 40.6 y). Across the five employment classifications, mean age ranged from 39.0-44.8 y. Moreover, there was good agreement (>20% of both males and >50 year olds) across seven of the tasks which firefighters felt limited by their physical capacity (Table 2.12). It thus appears the influence of age on the analysed ratings (Tables 2.7-2.10) reported were minimal. An adequate representation of these subgroups throughout the employee survey therefore lends support towards the survey employed being an appropriate instrument in developing age- and gender-neutral (legally defensible) standards.

Importantly, further differences across employee subgroups, such as job classification (occupational role), can affect the validity and reliability of epidemiological studies (LaPorte *et al.*, 1985) and this must be considered when evaluating job assessment instruments such as the employee survey. For example, respondents in this study, such as appliance drivers, will presumably rank such tasks (*e.g.* the location and connection of a hydrant) higher compared to a Station Officer. These possible inflation of rankings could be due to the expectation that drivers work at a higher intensity on arrival than Station Officers at a typical fire suppression, especially when locating and operating a hydrant (personal communication, focus groups). In contrast, a Station Officer's role for this task is far less physically demanding, since these firefighters delegate tasks to other personnel whilst constructing a tactical fire-fighting strategy. However, the statistical comparison of drivers and Stations Officers responses unfortunately cannot be analysed within the current data sample as drivers can encompass all employment classifications (permanent, retained, metropolitan and regional) below that of Station Officer.

Respondents have been shown to deliver inconsistent and variable responses in longer and multiple-part surveys (Dengler *et al.*, 1997), displaying the problematic nature of these instruments. Thus, it could be argued that, while necessarily detailed, the employee survey instrument was too long, especially given this inconsistency is less problematic in shorter questionnaires (Wilson *et al.*, 1990). This is relevant to the questionnaire used in this study, as many employees complained that it was too long and they became disinterested towards the end of the survey. However, to provide consistency of measurement and an adequate assessment of the possible associated factors under study, it is critical to assess all variables in depth when assessing physical activity (LaPorte *et al.*, 1985). Thus, it was deemed necessary for the employee survey to be lengthy, to thoroughly analyse the respective variables in adequate detail. The employee survey utilised in this study also aimed to engage the respondents with clear, concise fire-fighting language to ensure that the respondents fully comprehended what was being asked (Morgeson and Campion, 1997; personal communication, Fire & Rescue NSW). This inherently enhances the reliability of the testing instrument, according to job analysis reviews (Morgeson and Campion, 1997).

On the basis of these analyses, a trade-task list entailing fifteen essential, physically demanding fire-fighting tasks were established. The processes employed lend support to the valid representation of physically demanding activities associated with fire fighting, as performed in regional and metropolitan NSW. These observations allow for the evaluation and quantification of each trade task (Chapter Three). Contemporary firefighters face numerous physical and physiological demands when completing these tasks (Davis *et al.*, 1982; Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001a; Barr *et al.,* 2010). Indeed, metabolic heat production and heat storage will rise in accordance with increases in fire-fighting intensity (Carter *et al.*, 1999; Baker *et al.*, 2000) and this strain is excessive under extreme heated environmental conditions (Romet and Frim, 1987; Smith *et al.,* 2001).

Furthermore, physiological strain in these conditions will be further exaggerated by the personal protective ensemble worn by firefighters, restricting evaporative heat exchange with the external environment (Nunneley, 1989) and increasing cardiac output and skin blood flow (Fogarty, *et al.*, 2004). It is thus appropriate to determine the physical and physiological attributes necessary to cope with these demands whilst performing these fire-fighting duties in an optimal and safe manner (Chapter Three).

2.5 CONCLUSION

The final trade task list illustrated in Table 2.14 (adapted from Table 2.13) is believed to represent a valid and representative subset of essential, physically demanding activities associated with fire fighting as performed in regional and metropolitan NSW. This was achieved through the uniformity of responses from the information derived from focus groups, an evaluation of task importance, effort, duration and frequency through an employee survey and finally a filtration process determining task inclusion and exclusion criteria. The broad range of representations across the various subgroups (age, gender, employment classification and experience) provide further evidence the final trade task list is a valid representation of the most essential and physically demanding activities associated with fire fighting. Further research is required to evaluate and quantify each trade task to determine the physical and physiological attributes necessary to perform these fire-fighting duties in an optimal and safe manner. This will take place in Chapter Three, the second study of this dissertation.

Table 2.14: Recommended trade tasks and mean durations (minutes) for detailed investigation in Phase Two of this project.

Task	P-Metro	R-Metro	P-Region	R-Region
Rolling out uncharged hose lines: 70 mm	3			
Hydrant: locating and connecting	6	5	10	
Coupling and uncoupling hoses	2	4	6	2
Drag 70-mm charged hose: horizontal	7	4	10	5
Stair climb with PPE, BA, hose	10	7	13	8
Prolonged use of 38-mm hose	32	24	32	24
Prolonged use of charged hose: 70 mm (two people)	38	19	30	17
Fire attack: prolonged crawl, kneel, crouch, squat	18	18	24	16
Ladder use (10.5 m): 1-person, under run, stabilise	8	5	10	7
Rescue FF with PPE, BA: 1 person	8	10	12	12
Using spreaders and shears	20	14	24	19
Using sledge hammer to gain entry	3	4	7	5
Carry: ventilation fan (up stairs): 2 people	7	6	10	7
Hazmat: walking, manual handling (encapsulated)	30	18	32	20
Bush: drag charged hose (hilly, sloped, uneven)	58	21	50	24

Notes: P-Metro = permanent metropolitan; R-Metro = retained metropolitan; P-Region = permanent regional; R-Region = retained regional.

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CHAPTER 3: QUANTIFICATION OF PHYSICAL AND PHYSIOLOGICAL DEMANDS OF FIRE FIGHTING

3.1 INTRODUCTION

Many authors have utilised physical and physiological measures as a means to quantify the minimal energy expenditure required to perform fire-fighting tasks (Lemon and Hermiston, 1977b; Davis *et al.,* 1982; Gledhill and Jamnik, 1992a; Bilzon *et al.,* 2001a), and to set physical employment standards for the recruitment of firefighters (Gledhill and Jamnik, 1992b; Rayson *et al.*, 2004). Organisations involved in occupations with heightened physical demands (such as fire fighting) will screen potential employees to maximise the recruitment process and to identify those best suited to deal with these demands. Indeed, these physiological employment standards are aimed at developing an increased worker capability and, consequentially, may lead to a decrease in injury rates (Cady *et al.*, 1985; Harvey *et al.*, 2008).

The critical legal and scientific steps within this process of developing physical employment standards have been established (Table 1.1). The second phase within this process is to observe, measure and quantify the demands of the essential, physically demanding fire-fighting trade tasks (Gledhill *et al.*, 2001; Chapter Two), and herein lies the purpose of the current investigation. This will assist in determining the criterion fire-fighting tasks for use in the development of screening tests. These tests must be legally defensible (Constable and Palmer, 2000; Doherty *et al.*, 2007; Jamnik *et al.*, 2010a), and reflect the physical demands of the most important and difficult trade tasks (Jamnik *et al.*, 2010a and 2010b).

The current entry level maximal aerobic power standard (45 $ml.kg^{-1}.min^{-1}$) for NSW firefighters are based upon Canadian firefighters and fire-fighting practise, determined almost 20 years ago (Gledhill and Jamnik, 1992a and 1992b). The operational requirements and equipment changes since this time (Fire & Rescue News, 2011) indicate a critical re-evaluation of the physical and physiological demands of contemporary fire fighting is necessary. However, quantifying these demands can be arduous. For instance, calculating metabolic demand in live fire situations becomes quite difficult, as open-circuit, expired gas analysis and ventilation systems will be damaged when measuring oxygen uptake in such conditions. Nevertheless, while heart rate can give estimations of the energetic requirements of fire-fighting trade tasks (Smolander *et al.*, 1985; Sothmann *et al.*, 1991; Bilzon *et al.*, 2001a), it is influenced by many extraneous factors which reduce its validity (Sothmann, 1991; Notley, 2012), such as external air temperature (Rowell, 1974), hydration state (Saltin, 1964) and altitude exposure (Mazzeo, 2008). Therefore, it is preferable to also obtain direct measures of oxygen consumption to represent the aerobic demand of fire-fighting tasks. Thus, to directly measure the demands of fire fighting it becomes necessary to simulate the essential, physically demanding tasks. However, these simulated tasks must provide an adequate representation of the demands of the real-time occupational tasks, as performed within the field (Jamnik *et al.*, 2010a and 2010b).

To provide prescriptive recommendations for the development of suitable screening tests for firefighters, the quantification of the demands of physically demanding trade tasks, as performed within NSW, must therefore take place. This will allow for the assessment of the physiological impact of the loads handled during fire fighting when also wearing personal protective equipment. This process should focus on tasks that impose the greatest physiological burden upon the individual (Sothmann *et al.*, 1992a; Sothmann *et al.*, 2004; Taylor *et al.*, 2010a). These tasks will then form the basis from which a firefighter screening test can be developed, so that task-specific tests can be established to replicate the full demands of the occupation (Bilzon *et al.*, 2001b, Garver *et al.*, 2005). The development of these screening tests will be the aim of Chapter Four of this dissertation. These tests will assist in identifying the physical and physiological capabilities necessary to perform fire-fighting tasks in an optimal and safe manner (Gledhill and Jamnik, 1992b).

3.1.1 Aims of the study

The aim of this study was to observe, quantify and evaluate the physical and physiological demands placed upon firefighters during the performance of essential, physically demanding trade tasks. The tasks chosen for this study were determined on the basis of the online survey responses and task distillation processes undertaken in Chapter Two (Phase One of this research), along with recommendations from the Management Team overseeing this project. This study follows Steps 8-10 in the procedural summary from the framework for developing legally defensible physiological employment standards (Table 1.1).

3.2 METHODS

3.2.1 Subjects

Overall, fifty-one firefighters participated in this study (mean age: 37.3 years; mean operational experience: 9.2 years; Table 3.1). Between eight and seventeen firefighters participated in each simulation representing the recommended fire-fighting tasks from Phase One of this research (Chapter Two). This research was approved by the Human Research Ethics Committee at the University of Wollongong (HE11//299). All subjects received an information package, and provided written, informed consent and completed a ParQ screening questionnaire (Thomas *et al.*, 1992) to exclude those at risk from cardiovascular strain or with a previous history of musculoskeletal injury. All subjects were volunteers, but the combination of subjects was chosen to obtain a relatively heterogenous sample. These volunteers were experienced, operational, metropolitan permanent firefighters. This was to ensure that selection bias (unrepresentative sample) would not affect data collection. Furthermore, male and female firefighters were drawn from a range of Fire Stations in an attempt to provide a representative mixture of task performance skills, ages, body sizes and fitness levels to not only prevent systematic sampling errors, resulting in the analysis of unrepresentative individuals, but also to reflect current operational firefighters within Fire & Rescue NSW. This process was conducted by Fire & Rescue NSW and was considered necessary, given the legal ramifications of discriminatory standard development and implementation (Barr and Flannery versus the Treasury Board of the Department of National Defence, 2006; Docherty *et al.*, 2007). These procedures must ensure the processes conducted in physical employment standard development do not discriminate against any subgroup within the community (Constable and Palmer, 2000; Docherty *et al.*, 2007; Payne and Harvey, 2010). Only one employment category has been utilised in this study, a possible limitation, access to other employment categories was not possible as determined by Fire & Rescue NSW. Whilst this is important to consider, it is believed this has not hampered the scientific process as conclusions from Chapter Two indicate all firefighters are expected to be able to conduct all occupational tasks regardless of

Table 3.1: Characteristics of all subjects participating in this study. Simulations correspond to the simulation numbers in Table 3.2.

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)	Simulations participated in
S1	SFF	46	10	171.20	86.80	1, 2
S2	SO	57	28	197.00	108.20	1, 2, 10, 11, 12, 13, 14, 15
S3	QFF	29	4	179.70	89.20	1, 2
S4	FF	23	1	171.00	65.00	1, 2, 10, 11, 12, 13, 14, 15
S5	FF	26	1	181.10	113.60	1, 2, 10, 11, 12, 13, 14, 15
S6	FF	25	2	182.90	82.30	1, 2, 10, 11, 12, 13, 14, 15
S7	SFF	46	20	168.50	82.30	1, 2
S8	SO	47	20	171.00	92.75	1, 2, 11, 12, 14
S9	SFF	42	9	163.00	84.20	1, 2
S10	QFF	47	9	173.00	91.05	1, 2, 10, 11, 12, 13, 14, 15
S11	LFF	34	10	179.00	97.10	1, 2, 10, 11, 12, 13, 14, 15
S12	SFF	39	13	178.50	95.30	1, 2
S13	SFF	45	10	179.50	95.40	1, 2
S14	SFF	37	13	184.50	91.15	1, 2, 10, 11, 12, 13, 14, 15
S15	SO	42	13	189.00	100.00	1, 2
S16	SFF	42	21	190.00	108.90	1, 2
S17	FF	32	3	185.00	79.75	3, 4, 5, 6, 7, 8, 9

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)	Simulations participated in
S18	SO	41	22	176.00	77.30	3, 4, 5, 6, 7, 8, 9
S19	FF	39	3	183.00	81.05	3, 4, 5, 6, 7, 8, 9
S20	QFF	33	4	177.00	78.55	3, 4, 5, 6, 7, 8, 9
S21	SO	49	24	177.00	102.55	3, 4, 5, 6, 7, 8, 9
S22	QFF	33	4	168.00	68.00	3, 4, 5, 6, 7, 8, 9
S23	SO	50	29	177.50	86.40	3, 4, 5, 6, 7, 8, 9
S24	FF	29	2	182.50	77.75	3, 4, 5, 6, 7, 8, 9
S25	QFF	26	3	189.00	89.00	3, 4, 5, 6, 7, 8, 9
S26	QFF	29	5	167.50	92.20	3, 4, 5, 6, 7, 8, 9
S27	SFF	41	6	161.10	55.30	3, 4, 5, 6, 7, 8, 9
S28	SO	44	15	177.00	70.70	3, 4, 5, 6, 7, 8, 9
S29	SFF	42	9	177.00	76.90	3, 4, 5, 6, 7, 8, 9
S30	SFF	46	8	179.50	69.50	3, 4, 5, 6, 7, 8, 9
S31	QFF	36	3	182.30	92.10	3, 4, 5, 6, 7, 8, 9
S32	FF	26	3	194.50	108.45	3, 4, 5, 6, 7, 8, 9
S33	QFF	25	4	175.00	72.20	9
S34	QFF	31	6	182.30	85.35	10, 11, 12, 13, 14, 15
S35	QFF	41	4	177.00	87.35	10, 11, 12, 13, 14, 15
S36	QFF	32	4	185.70	84.70	10, 11, 12, 13, 14, 15

Subject	Rank	Age (y)	Experience (y)	Height (cm)	Body mass (kg)	Simulations participated in
S37	SFF	25	7	179.00	76.95	10, 11, 12, 13, 14, 15
S38	SFF	40	11	184.30	94.60	10, 11, 12, 13, 14, 15
S39	SFF	47	8	169.70	90.20	10, 11, 12, 13, 14, 15
S40	SFF	47	10	186.30	88.90	10, 13, 14, 15
S41	QFF	26	6	168.80	62.50	10, 13
S42	FF	46	3	174.00	69.30	10, 14, 15
S43	SFF	41	13	178.80	94.45	10, 14, 15
S44	SO	36	13	171.00	90.10	16
S45	QFF	25	5	193.00	70.40	16
S46	FF	30	1	177.80	102.50	16
S47	QFF	35	4	181.40	87.25	16
S48	SO	52	28	173.80	87.10	16
S49	SFF	36	6	169.30	70.80	16
S50	SFF	38	7	184.40	80.70	16
S51	FF	28	1	180.60	71.85	16
Mean		37.3	9.2	178.54	85.41	-
SD		8.6	7.5	7.70	12.72	-

Notes: FF = firefighter, QFF = qualified firefighter, SFF = senior firefighter, LFF = leading firefighter, SO = Station Officer.

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employment classification.

For almost all simulations, firefighters participated as whole platoons. Due to the presence of each platoon's Station Officer, this process ensured that each simulation was performed at a realistic operational efficiency that was not affected by individual variability and unfamiliarity. This not only permitted quantification of the physiological attributes with ideal task performance (precise, reproducible and efficient), but also the strain, and possible consequences associated with failing to satisfy this standard.

3.2.2 Experimental overview

In total, fifteen occupational tasks (Table 3.2) were evaluated and quantified in this investigation, and these were conducted under controlled and simulated conditions, at work rates consistent with those encountered during fire-fighting operations. There was also an additional hot-fire cell search and rescue simulation (with and without heat and smoke). The design of each simulation was at the discretion of eight subject-matter experts (Senior Training Officers). These officers were identified by Fire & Rescue NSW for this purpose. Given the qualifications (qualified firefighters, senior firefighters, station officers, inspector and superintendent personnel) of these officers, this also ensured a high level of safety for the performing firefighters. The Research Team assisted in the development of these simulations, but ensured that the simulation still represented a realistically difficult operational scenario.

The intensity of these simulations was regulated by Station Officers, subject-matter experts and training officers to ensure work rates were consistent with those encountered during fire-fighting operations, but the final intensity was set by the firefighters performing the simulation. All contemporary equipment utilised in the simulations was designated by Fire & Rescue NSW. These procedures not only permitted the quantification of the physiological demands of operational performance, but also the physical and physiological attributes necessary for successful operational performance.

Table 3.2: Recommended fire-fighting tasks and observation durations (minutes) for this investigation. Data were derived from the study in Chapter Two of this dissertation, whereby a survey ($N = 1011$) was administered to all fire-fighting employees across the four firefighter classifications.

Task	P-Metro	R-Metro	P-Region	R-Region
Simulation 1: Hazmat incident	30	18	32	20
Simulation 2: Motor-vehicle rescue	20	14	24	19
Simulation 3: Rolling out hose (70 mm)	3	1	6	2
Simulation 4: Coupling hoses	2	4	6	2
Simulation 5: Locating and connecting to hydrant	6	5	10	4
Simulation 6: Drag charged 70-mm hose (lateral)	7	4	10	5
Simulation 7: Fire attack	18	18	24	16
Simulation 8: Firefighter down - rescue	8	10	12	12
Simulation 9: Bushfire incident	58	21	50	24
Simulation 10: Stair climb dragging charged hose	10	7	13	8
Simulation 11: Prolonged use of hose (38 mm)	32	24	32	24
Simulation 12: Prolonged use of hose (70 mm)	38	19	30	17
Simulation 13: Ladder use (10.5 m)	8	5	10	7
Simulation 14: Stair climb with ventilation fan	7	6	10	7
Simulation 15: Using sledge axe to gain entry	3	4	7	5

Notes: P-Metro = permanent metropolitan; R-Metro = retained metropolitan; P-Region = permanent regional; R-Region = retained regional.

3.2.3 Experimental conditions

3.2.3.1 Location of the tests

Firefighters were tested across various training centres and Fire Stations across the state. Table 3.3 provides the location of each simulation. These sites were chosen by Fire & Rescue NSW depending on the simulations performed. This ensured that each simulation was able to be performed in such a manner as to best represent the physiological demands encountered during typical fire-fighting operations.

3.2.4 Experimental protocol

Fifteen occupational tasks (Table 3.2), plus an additional hot-fire cell search and rescue simulation (with and without heat and smoke), were conducted under controlled and simulated conditions. Since the performance and analysis of these simulations was critical to the next phase of research, which focuses on the development of screening tests with potential for individual test items, they are outlined as individual task simulations in the proceeding subsections.

3.2.4.1 Simulation one: Hazmat (hazardous materials) incident

Sixteen firefighters participated in this simulation (fifteen men and one woman; Subjects 1-16; Table 3.1). Eight firefighters were tested in the morning and another eight in the afternoon. This simulation was established to replicate the physiological demands a contemporary firefighter would face during a typical hazardous material incident. Such an incident would entail the carriage of numerous items proceeding the spillage of hazardous materials involved in, for example, an oil semi-trailer crash. This simulation commenced with a 5-min seated rest, with two individuals investigated simultaneously. Firefighters wore station-wear clothing (mean mass: 1.4 kg), breathing apparatus (mean: 11.44 kg), an encapsulating ensemble (mean: 7.7 kg) and data acquisition system (1.82 kg). Firefighters wore the encapsulating ensemble over station-wear garments with the head and partial chest exposed to wear the respiratory gas analysis equipment, as this prevented full encapsulation. An exclusion zone was established 64 m from the hazard. This zone was established to represent the area to which firefighters carry items necessary for removal from a hazardous area. Firefighters commenced the simulation by walking into this zone

Table 3.3: Locations of task simulations and the participating fire-fighting platoons.

Location	Participating fire station platoons	Simulations performed
Ingleburn Training Centre	Hazmat Advisory Response Team, Hurstville, Liverpool and City of Sydney.	Hazmat, motor-vehicle rescue
Londonderry Training Centre	Blacktown, Kellyville, Mount Druitt and Seven Hills	Bowling 70-mm hose, coupling hoses, locating and connecting to a hydrant, dragging charged 70-mm hose, fire attack, firefighter down (rescue)
Hornsby bush fire training area	Blacktown, Kellyville, Mount Druitt and Seven Hills	Bush fire (dragging charged hose forwards: uneven terrain)
Alexandria Training College	Alexandria, Hurstville, Liverpool and City of Sydney, Darlinghurst and Redfern	Stair climb dragging charged hose, prolonged use of 38-mm hose, prolonged use of 70-mm hose, ladder use (10.5 m), carrying ventilation fan up stairs, using sledge axe to gain entry and the hot-cell structural search and rescue

carrying a ladder (16 kg; Figure 3.1). All firefighters walked an identical route into and out of the hazard area while walking across three surfaces (bitumen, gravel and an elevated concrete slab). Figure 3.1 illustrates the removal (from a simulated truck tray 1.1 m above ground) of eight items to beyond the exclusion zone: seven gas cylinders (8.45, 9.55, 18.50, 20.65, 21.45, 40.30 and 52.25 kg) and one plastic container (21.85 kg). The 8.45 and 9.45 kg cylinders were carried individually with the remaining cylinders being carried in pairs. The simulation ended when all equipment had been removed beyond the exclusion zone. The average duration of these simulations was 15.24 min (SD 2.47). Each firefighter also performed the next simulation (motor-vehicle rescue), resting for a minimum of 30 min between successive simulations. Ratings of perceived exertion were recorded during and after the task.

3.2.4.2 Simulation two: Motor-vehicle rescue (spreaders, shears: in pairs)

The same firefighters (fifteen men and one woman; Subjects 1-16; Table 3.1) participated in this activity. This simulation also commenced with a 5-min seated rest, with each firefighter resting at least 30 min after the first simulation. This simulation was established to replicate the physiological demands a contemporary firefighter would face during a typical motor-vehicle rescue incident. Such an incident would entail the carriage of heavy equipment to remove doors from a car to rescue a trapped civilian. This was again a paired simulation, but now with firefighters wearing station wear clothing or bush fire jackets, protective boots (mean: 2.61 kg) and rescue helmets (mean: 1.48 kg). All tools were positioned on a salvage sheet and the activity commenced at this position approximately 10 m from the vehicle. The aim of the activity was to remove two doors from the side of a damaged vehicle. Figure 3.2 illustrates the different postures this simulation entailed. One pair from every three firefighter pairs also removed the vehicle roof. The simulation ended for each pair when vehicle entry was achieved and equipment was returned to the salvage sheet. The average duration of these simulations was 13.57 min (SD 5.40), with ratings of perceived exertion recorded during and after the task.

3.2.4.3 Simulation three: Rolling (bowling) out 70-mm hose (individual)

Sixteen firefighters participated in this task simulation (fourteen men and two women;

Figure 3.1: Firefighters performing a hazmat incident simulation. Clockwise from top left: firefighters at rest with MetaMax 3B system and encapsulating ensemble; carrying a ladder to the exclusion zone; carrying a cylinder to the exclusion zone; examination of a large cylinder; examples of the cylinders utilized in the hazmat simulation; firefighter climbing ladder to the simulated truck tray (1.1 m).

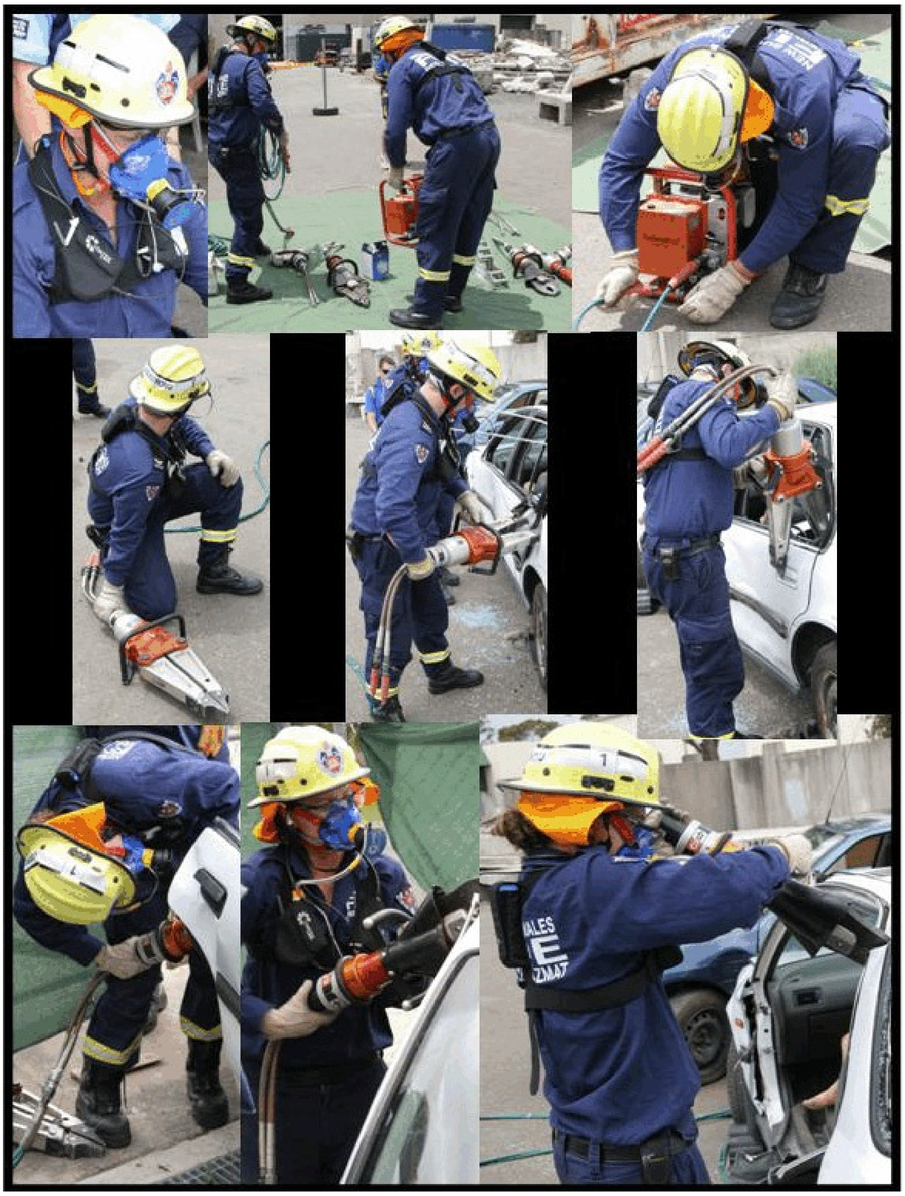

Figure 3.2: Firefighters performing a motor-vehicle rescue simulation. Top: Firefighters wearing the MetaMax 3B at rest and preparing the rescue equipment; Middle: Firefighters wearing the MetaMax 3B during the simulation while using the spreaders (19.5 kg) to remove doors; Bottom: Firefighters wearing the MetaMax 3B during the simulation while using the shears to remove the doors and roof (13 kg).

Subjects 17-32; Table 3.1), with eight tested in the morning and eight tested in the afternoon. The proceeding simulations (three to six) were performed in sequence, though with suitable amounts of rest separating each activity. These simulations included (in chronological order): Rolling (bowling) out 70-mm hose, coupling hoses, locating and the connection of a hydrant and dragging a charged 70-mm hose (lateral: individual). This grouping sequence was utilised to represent a typical operational scenario a contemporary firefighter would face on the arrival at an incident. For all activities within this group of simulations, firefighters wore full thermal protective and station-wear clothing (mean: 4.72 kg), helmets (mean: 1.39 kg), breathing apparatus (mean: 11.53 kg), protective boots (mean: 2.58 kg), radio (1.10 kg) and expired gas analysis and ventilation system (1.82 kg). The group simulation commenced with a 5-min seated rest.

This first activity of this group simulation involved rolling (bowling) out two, 70-mm hoses (16.6 kg each) prior to using these hoses to connect the hydrant to the appliance (pump). This was to simulate hose preparation at a typical fire suppression incident. This task involved the following steps: roll one, 70-mm hose diagonally; carry one end of this hose plus a second 70-mm rolled hose, fully extend the first hose 15 m; place the first hose on the ground; roll out the second 70-mm hose; pick up one end of this hose and walk to hydrant (24 m); place the hose end over the hydrant (Figure 3.3). Each of these distances were fixed, with markers used to clearly show each point. This completed the task which involved a walking distance of 41 m. The average duration of these simulations was 1.68 min (SD 0.34), with ratings of perceived exertion recorded after the task.

3.2.4.4 Simulation four: Coupling hoses (individual)

After completing the hose roll, the same firefighters (Subjects 17-32; Table 3.1) participated in the hose coupling task. This task was representative of the physical demands a firefighter would face when connecting hoses to the appliance, a necessity for the successful suppression of a fire. As this task was the second part of a series of four task simulations (using identical clothing protective equipment), participants rested for 2 min (standing) before commencing the activity, which started from where the previous simulation (rolling out 70-mm hose) finished. Firefighters walked from the hydrant to the

Figure 3.3: Firefighters (clockwise from bottom left) locating and connecting a hydrant; removing items from the appliance as part of the hydrant simulation; coupling hoses on the ground and on the appliance; roll (bowling) out 70-mm hose.

appliance (41 m), and coupled (connected) the hose to the appliance using either both hands or the coupling spanners to make this connection (Figure 3.3). Participants then walked 15 m to the point where the two ends of the two 70-mm hoses lay on the ground. These hoses were then coupled (using hands or coupling spanners). Finally, firefighters walked 15 m to the hydrant and coupled the hose to the hydrant (using hands or coupling spanners). Each distance was fixed, with markers used to clearly show each point. The simulation ended with the final connection at the hydrant, with the full simulation lasting an average of 1.14 min (SD 0.34), with ratings of perceived exertion recorded after the task.

3.2.4.5 Simulation five: Locating and connecting hydrant to appliance (individual)

After completing the hose coupling, these same firefighters (Subjects 17-32; Table 3.1) continued this grouped simulation, which now involved firefighters locating and connecting a hose to a fire hydrant. This task was the third in a series of four task simulations (identical clothing and protective equipment). Before commencing, participants rested for 2 min (standing), which started with a 41-m walk to the appliance. Firefighters opened the sliding doors on the side of the appliance to remove one, 70-mm hose, hydrant, standpipe and breaching piece (Figure 3.3). All items were carried as quickly as possible (the pace one would experience at a typical fire incident) to a hydrant marked 70 m away. Some firefighters chose to carry all items at once, thus performing the task in one trip (70-m), while others elected to make two trips (210 m: 70 m to hydrant, 70-m return and the final 70-m trip to the hydrant). Each distance was fixed, with markers used to clearly designate these points. The simulation ended at the hydrant, and lasted an average of 2.78 min (SD 0.83), with ratings of perceived exertion recorded after the task. After completing this task, firefighters rested for 5 min (seated) before commencing the final simulation within this group of activities.

3.2.4.6 Simulation six: Dragging charged 70-mm hose (lateral: individual)

Finally within this group of four simulations, the same group of 16 firefighters (Subjects 17-32; Table 3.1) participated in dragging a charged, 70-mm fire hose. This simulation was established to replicate the physiological demands a contemporary firefighter would face during a typical fire suppression incident. Such an incident would entail the carriage and dragging of a charged 70-mm hose. This task was the final activity of four consecutive simulations, designed to last 7 min in total. Three markers were placed in a line on the ground, with each being 4 m from the next. Firefighters were instructed to move (drag) a fully charged 70-mm hose laterally, moving between adjacent markers as quickly as possible. At each marker, participants maintained a stationary position for 30 s, before moving to the next position. This simulated both moving of the hose laterally, and redirecting it to a different part of a building. Movement between these cones was repeated until 7 min had elapsed. The mass of water in this hose was estimated to be ~ 115 kg, with 7-8 kg being off the ground. These distances were fixed with markers. The simulation lasted an average of 7.09 min (SD 0.03), with ratings of perceived exertion recorded during and after the task. Once completed, firefighters rested fully before commencing other simulations.

3.2.4.7 Simulation seven: Fire attack (in pairs)

Following a full recovery from the previous four simulations, the same 16 firefighters now participated in a fire attack simulation (Subjects 17-32; Table 3.1). This simulation was established to replicate the physiological demands a contemporary firefighter would face during a entry and indoor fire suppression incident. Such an incident would entail the carriage and dragging of a charged 38-mm hose and performing various manoeuvres to subdue the fire. This simulation was performed in pairs, with one leading and holding the hose branch, while the other assisted by helping to drag two lengths of charged 38-mm hose. Firefighter pairs would reverse roles, such that each firefighter participated in this simulation as both the lead and assisting firefighter. Thus, data were collected for sixteen firefighters is each position. The mass of water in two lengths of 38-mm hose was estimated to be about 70 kg. A 5 minute seated rest preceded the simulation and firefighters again wore full thermal protective clothing and self-contained breathing apparatus, as described above (total mean mass: 23.14 kg).

All activities were performed in a crouched position to more realistically simulate a residential fire, in which very hot air, and possibly also flames, prevented an upright posture. Some firefighters preferred to operate in a kneeled position also. The following sequence was replicated by each firefighter holding the branch: move 2.3 m to the door; cool door; make entry; move to a point inside the building (18.2 m from start); walls were placed at 7.9 m and 12.2 m (firefighters negotiated both); turn and move 8 m to fight a second fire (now 15.5 m from start); make way back to the start. Throughout this simulation, gas cooling and the knocking down of fire were simulated. For the firefighters assisting, the sequence was identical, but this firefighter was between 1-3 m behind the first. The second firefighter ensured the hose was able to be freely dragged and that the first firefighter had sufficient hose to perform the tasks and to continue moving forwards. These distances were fixed with markers. The simulation lasted an average of 4.16 min (SD 0.63), with ratings of perceived exertion recorded during and after the task. Once completed, firefighters rested fully before commencing the next simulations.

3.2.4.8 Simulation eight: Firefighter down: one-person rescue (individual)

Following a full recovery from the fire attack simulation, the same group of 16 firefighters (Subjects 17-32; Table 3.1) completed a one-person, firefighter rescue simulation. In this task, a new fire attack simulation was used to provide a lead-up activity and replicate a scenario where the lead firefighter of the pair had collapsed. Thus, the lead firefighter needed to be rescued by the second firefighter. As such, the firefighter down would be wearing complete thermal protection equipment and self-contained breathing apparatus, and the rescue would be performed by a single individual, also wearing full turnout clothing and breathing apparatus. However, to standardise this rescue across all participants, and to ensure that the rescued firefighter was representative of those employed by Fire & Rescue NSW, one of the Training Officers (85.15 kg plus 20.42 kg of protective equipment and breathing apparatus: total mass = 106.57 kg) was the rescued firefighter for all these simulations (Figure 3.4).

The preliminary fire attack proceeded as follows: move 2.3 m to the door; cool door; make entry; upon entry move to the right towards the end of the room (4.8 m from start); search room and leave; move to a second room and enter (now 6.6 m from start); search room and leave; move to a third room and enter (now 11.2 m from start); search room; fallen firefighter was always at the same point in this room; drag fallen firefighter from the third

Figure 3.4: Firefighters wearing the MetaMax 3B whilst performing a one-person simulated firefighter rescue of a Training Officer (85.15 kg plus 20.42 kg of protective equipment and breathing apparatus: total mass = 106.57 kg).

room to a point outside the building. The total drag distance was 10.5 m, and the complete simulation lasted an average of 3.88 min (SD 0.66). Once completed, no other simulations were performed by this group of firefighters on that day

3.2.4.9 Simulation nine: Bushfire (dragging charged hose forwards: individual)

Sixteen firefighters participated in this simulation (fifteen men and one woman; Subjects 17-25; 27-33; Table 3.1). This simulation (Figure 3.5) was established to replicate the physiological demands a contemporary firefighter would face during a typical bush fire suppression incident. Such an incident would entail the carriage and dragging of a charged 38-mm hose over various terrains. This activity was designed to last approximately 52 min, and it was completed as a continuous task performed over two different bushland terrains in succession: hilly and flat. Firefighters wore station-wear clothing, bush helmet, bushfire jacket, radio and data acquisition equipment (mean total mass: 9.42 kg). Firefighters were briefed on the area by the Training Officer, who was familiar with both the area and how firefighters tackled the task as the area had recently been exposed to a controlled burn as part of routine bush fire prevention operations. Each firefighter rested for a minimum of 5 min prior in a seated position to commencing the bush fire simulation. Firefighters then were allocated to commence either on a hilly terrain or on flatter terrain.

Each firefighter was instructed to move to the designated area and to simulate extinguishing a region of bush land. Each firefighter was responsible for the movement of one length (30 m) of fully charged, 38-mm hose (~35 kg). The branch remained closed during the entire simulation. The second firefighter was responsible for moving the hoses attached to this single length but no physiological data was collected from this individual. The maximum lengths of hose used per simulation was three. For 13 min, the firefighter walked away from the point of origin, simulating extinguishing burning bush. Once this 13 min was complete, firefighters were instructed to move quickly and extinguish a spot fire 15-25 m away. This activity also lasted 13 min, and included firefighters returning to the point of origin, during which they continued to knock down, mop-up or extinguish spot fires. At the end of 26 min, the first terrain was deemed to have been completed, and without rest,

Figure 3.5: Clockwise from top left: Firefighters simulating the dragging of a charged hose over flat and hilly terrain; firefighters dragging a charged 38-mm hose into a building and up stairs; the prolonged use of 70-mm hose (pairs); the prolonged use of 38-mm hose (individual).

firefighters switched over to the second terrain to complete the same activities. Half of the firefighters commenced the task on the hilly terrain while the other half started the simulation on the flatter terrain. The simulation lasted an average of 52.33 min (SD 0.01), with ratings of perceived exertion recorded during and after the task.

3.2.4.10 Simulation ten: Stair climb dragging charged 38-mm hose (forwards: in pairs)

Seventeen firefighters participated in this block of six fire-fighting simulations (fifteen men and two women: Subjects 2, 4, 5, 6, 10, 11, 14, 34-43; Table 3.1). This simulation (Figure 3.5) was established to replicate the physiological demands a contemporary firefighter would face during a typical tower climb and fire suppression. Such an incident would entail the carriage and dragging of a charged 38-mm hose and door entry tools up flights of stairs. This simulation was performed in pairs, and within the high-rise structure at the Alexandria Training College. Prior to commencing, each firefighter completed 5 min of seated rest. Firefighters wore station-wear clothing, turnout gear, breathing apparatus, radio and gas analysis system (mean total mass: 23.8 kg). From a designated starting point, both firefighters walked 7.3 m through a ground-level doorway to the stairs, and ascended 64 stairs (4 storeys). Each participant was instructed to ascend at the pace that would be used during a high-rise walk up. The horizontal displacement per storey was 9.7 m, and the vertical displacement was 4.2 m per storey. Each step was 0.26 m in height, and each storey had a landing midway between the upper and lower levels, with eight steps above and below each landing. The simulation ended at the fourth storey. Thus, the total horizontal distance travelled was 38.9 m, whilst the vertical displacement was 16.8 m.

The leading firefighter was positioned on the branch of a fully charged 38-mm hose, with the second firefighter assisting by moving the hose, remained approximately one hose length behind (30 m) of the leading firefighter. That is, the leading firefighter had to manipulate this hose, and the mass of the water that it contained (~35 kg). The second firefighter carried door entry tools, including a halligan tool (5.8 kg) and sledge hammer/axe (4.5 kg). The method by which each team went about this task varied among pairs, and according to the experience of each pair. Physiological data were collected on both firefighters simultaneously, and the simulation lasted an average of 2.75 min (SD

0.80), with ratings of perceived exertion recorded during and after the task.

3.2.4.11 Simulation eleven: Prolonged use of 38-mm hose (lateral movement: individual)

Fourteen firefighters participated in this activity (twelve men and two women; Subjects 2, 4, 5, 6, 8, 10, 11, 14, 34-39; Table 3.1). Some data from Subject 8 were lost due to technical failure, and all data were lost for one firefighter. Information for this second individual has not been included in any part of this study. This simulation (Figure 3.5) was established to replicate the physiological demands a contemporary firefighter would face during a typical fire suppression using a 38-mm hose. Such an incident would entail the carriage of a charged 38-mm hose in a upright, stationary posture for a sustained period of time. This activity was designed to last approximately 15 min, and followed a 5-min seated rest. Firefighters wore the clothing and equipment described above (mean total mass: 23.8 kg). Each firefighter was instructed to hold a 38-mm hose and to direct water onto a wall 16.4 m away. The hose pressure was set at 700 kilopascals (kPa), providing a water flow of 300 $L.min^{-1}$. This activity required firefighters to move between a set of three markers, spaced 5 m apart. At the end of each minute, and on the command of the researcher, firefighters moved between a set of three markers. For these movements, the branch was closed and the hose was dragged to the new position, with the branch being opened again after the new position was reached and the firefighter was stationary. Thus, 15 positional changes were completed by each firefighter. Firefighters could change posture and position as required, but not move away from the marker until instructed. The simulation lasted an average of 15.36 min (SD 0.25), with ratings of perceived exertion recorded during and after the task.

3.2.4.12 Simulation twelve: Prolonged use of 70-mm hose (stationary: in pairs)

Fourteen firefighters participated in this activity (twelve men and two women: Subjects 2, 4, 5, 6, 8, 10, 11, 14, 34-39; Table 3.1). As per the 38-mm hose simulation, this activity lasted approximately 15 min, and followed a 5 min seated rest. Firefighters wore the clothing and equipment described above (mean total mass: 23.8 kg). In this case, firefighters worked in pairs, holding a 70-mm hose, and directed water onto a wall target

16.4 m away. The hose pressure was set at 700 kPa, which elicited a water flow 750 $L.min^{-1}$. This water flow was greater than the 38-mm due to the larger diameter, and thus volume, of the 70-mm hose. The branch of the 70-mm hose was open for the entire simulation, and both firefighters remained relatively stationary at a designated point during the simulation. Firefighters were allowed to change posture and position the hose as required, but the firefighter on the branch remained in that position throughout the simulation (Figure 3.5), and neither firefighter left the hose. The simulation lasted an average of 15.40 min (SD 0.20), with ratings of perceived exertion recorded during and after the task.

3.2.4.13 Simulation thirteen: Ladder use (10.5 m; in pairs)

Fifteen firefighters participated in this activity (thirteen men and two women: Subjects 2, 4, 5, 6, 10, 11, 14, 34-41; Table 3.1). This simulation (Figure 3.6) was established to replicate the physiological demands a contemporary firefighter would face during a typical external tower-climb incident. Such an incident would entail the removal, carriage, raise, climb and under-run of a 10.5-m extendable ladder. Firefighters performed this simulation in pairs, wearing the clothing and equipment previously described (mean total mass: 23.8 kg). However, only one firefighter performed the more difficult aspects of the simulation in each instance, whilst the other merely assisted. Thus, the working firefighter completed the following tasks: climbing onto the appliance to release and lower the ladder; carrying the ladder 32 m (one firefighter holding each end); under-running the ladder to raise it alone; ascending the ladder (to the fourth rung above the top of the building: approximately 25 rungs or 8.1 m); descending the ladder; lowering the ladder; carrying the ladder; climbing onto the appliance to return and correctly stow the ladder. The assisting firefighter helped by keeping the ladder balanced during its carriage and supporting the ladder when it was being raised (under-run), during the ladder ascent and when it was being lowered. This task was designed to replicate a scenario where a ladder would be required to ascend into, or onto a two-storey building. The simulation lasted an average of 5.39 min (SD 1.10), with ratings of perceived exertion recorded during and after the task.

Figure 3.6: Clockwise from left: firefighters climbing and raising the ladder as part of the 10.5-m ladder simulation; ventilation fan carry up stairs (pairs); using sledge hammer to gain entry past a steel door.

3.2.4.14 Simulation fourteen: Carrying ventilation fan up stairs (in pairs)

Eighteen firefighters participated in this activity (sixteen men and two women; Subjects 2, 4, 5, 6, 8, 10, 11, 14, 34-40, 42, 43; Table 3.1). This simulation (Figure 3.6) was established to replicate the physiological demands a contemporary firefighter would face during the removal of noxious gases and smoke from a tower. Such an incident would entail the carriage of a ventilation fan up flights of stairs. Prior to commencing the activity each firefighter rested for a minimum of 5 min, and again performed the simulation in pairs, wearing clothing and equipment described above (mean total mass: 23.8 kg). On either side of the ventilation fan (35 kg) a firefighter was positioned holding the fan by the handles provided at thigh height. The simulation begun with both firefighters walking 7.3 m from a designated starting point through a ground-level doorway to the stairs, and ascending 64 stairs (4 storeys). Each participant was instructed to ascend at the pace similar to that used during actual task performance (that experienced during a typical fire incident). The horizontal displacement per storey was 6.9 m, and the vertical displacement was 2.9 m per storey. Each step was 0.26 m in height, and each storey had a landing midway between the upper and lower levels, with eight steps above and below each landing. The simulation ended at the fourth storey. Thus, the total horizontal distance travelled was 38.9 m, whilst the vertical displacement was 16.6 m. The simulation lasted an average of 1.51 min (SD 0.29), with physiological data collected on both firefighters simultaneously, and ratings of perceived exertion recorded at the completion of the task.

3.2.4.15 Simulation fifteen: Using sledge hammer/axe to gain entry (individual)

Sixteen firefighters participated in this task simulation (fifteen men and one woman; Subjects 2, 4, 5, 6, 10, 11, 14, 34-40, 42, 43; Table 3.1). This simulation (Figure 3.6) was established to replicate the physiological demands a contemporary firefighter would face during the forced entry to a building. Such an incident would entail the dynamic use of a sledge axe on a door or entry point. Prior to commencing this simulation, each firefighter completed 5 min of seated rest. This activity was designed to last approximately 2.5 min and firefighters were dressed in clothing and equipment previously described (mean total mass: 23.8 kg). This simulation focussed on firefighters gaining entry to a room via a locked aluminium door, using the sledge hammer/axe (4.5 kg). The participants could hit any part of the door, but if it was not opened after five attempts, the door was opened by the instructor. Immediately, the firefighter walked approximately 5 m into an open room, across to a wall pillar that was lined with spare tyres and punching bags. The task now required each firefighter to continue to hit these tyres for a further 2 min. This was designed to replicate a scenario where a firefighter was unable to gain entry, but was required to repeatedly attempt to break through the door, as may occur occasionally with a steel door. However, this extended simulation permitted the collection of more representative data, since the demands of such high-intensity work cannot be evaluated if the duration is too brief (approximate steady state will not be reached; Sheppard *et al.,* 1968; Nielson *et al.*, 2010). These simulations lasted an average of 2.50 min (SD 0.14), with ratings of perceived exertion recorded at the completion of the task.

3.2.4.16 Simulation sixteen: hot-cell rescue

Though outside the fifteen essential, physically demanding trade-tasks, this simulation was included at the request of the research team. This request was put forward as the hot-cell rescue provided an opportunity to compare previously completed separate simulations with similar tasks completed in series under the addition of thermal strain. These single set of tasks, performed as one simulation, have high ecological validity[3]. Thus, to a degree, data collected could potentially validate, or least lend support to, the data collected for the previously completed separate simulations. Preliminary data has previously been collected for similar tasks (Taylor *et al.*, 2010b). Eight firefighters participated in this simulation (seven men and one woman; Subjects 44-51; Table 3.1).

This simulation occurred within the hot-fire cell at the Alexandria Training College (Figure 3.7). This is a three-storey, concrete structure containing steel stair cases and floors. The tasks performed by each firefighter were wholly controlled by training officers, and involved the dragging of a charged hose to the third floor, the rescue of two victims (70-kg and 50-kg dummies) and various other activities dictated by the training officers.

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[3] In occupational terms, ecological validity refers to the materials, settings and methods of an investigation which approximate the occupation, as performed in real-life, under examination.

Figure 3.7: The structural search and rescue simulation (hot-fire cell). Clockwise from top left; the hot cell tower; stairs within the hot cell (storeys one to two); firefighters preparing to enter the tower wearing MetaMax 3B; firefighters preparing to enter the hot-fire cell with smoke; birds eye view of the inside of the hot-fire cell.

Each firefighter performed the simulation twice (once under heat and smoke, and once without). Six platoons supported this activity, with two platoons fulfilling the roles of experimental subjects (one person at a time) and with one firefighter from the other platoons accompanying each experimental firefighter, and providing assistance as would occur within a structural fire scenario. This rotation of firefighters minimised the strain encountered by any one firefighter, and ensured that each of the experimental firefighters commenced the simulation in a well-rested and normothermic state. Firefighters wore full thermal protective and station-wear clothing, protective boots, breathing apparatus, helmets, radio (1.1 kg) and data acquisition system (mean total mass: 24.10 kg).

The average temperature of the cell was regulated between 68-73°C, but varied throughout the cell. The researcher did not accompany the firefighters on the simulation. The visibility in the cell was practically zero considering the lack of windows, extinguishment of lights and the prevalence of smoke. The durations of this simulation were set by several criteria. Given elevations in core temperature are a function of both exposure time and work rate, evaluating the impact of a more prolonged thermal simulation was of interest to the author, as firefighters may be required to exit the building, change breathing apparatus and re-enter the building. Therefore, the first criteria asked firefighters to continue the simulation as long as possible, and this may include changing the breathing apparatus. One firefighter was able to continue the simulation beyond the use of one set of breathing apparatus.

Secondly, the attainment of a core temperature greater than 39.5°C (checked on each exit from the cell) would signal a firefighter withdrawal. Two firefighters reached this temperature limit. Firefighters were free to withdrawal at any time. One firefighter asked to be withdrawn due to fatigue, and, on withdrawal, was found to have a core temperature of 39.35°C.

Thirdly, if any firefighter's air cylinder (found within the self-contained breathing apparatus) pressure fell below 5 mega pascals (MPa), a warning signal was triggered, and the firefighter immediately exited the building. Four firefighters withdrew in accordance with this criterion. However the core temperatures of these individuals were greater than

39°C and hence were not asked to continue. The final criterion dictated the termination of the simulation if the Training Officers felt that firefighter health and safety was at risk. One firefighter was withdrawn on this basis. These simulations lasted an average of 25.64 min (SD 5.10), with ratings of perceived exertion being recorded at the conclusion of the simulation.

On the day following the first of these simulations, firefighters replicated each scenario, but now wearing the portable expired gas analysis equipment (Figure 3.8). The average air temperature of the cell on the second day was 24.6°C, but varied throughout the cell. The researcher accompanied the firefighters during the simulation. While all lights were extinguished as per the first simulation, there was no heat or smoke, thus the firefighters could adjust to the light over the duration of the simulation. Each experimental firefighter replicated their own individual scenario during the first simulation as instructed by the Training Officers and ratings of perceived exertion were recorded upon the completion of specific sub-tasks as determined by the research team. Each firefighter's scenarios are listed below. These replications lasted, on average, 19.57 min (SD 4.22), with ratings of perceived exertion recorded during and after the task.

Simulation scenarios (day two):

Subject 44:

Initial search with hose from ground to top of third floor
50-kg dummy removed from third floor and dragged to ground floor
Dragged 50-kg dummy back up to the third floor
Walked down from third floor (dragging hose) to ground floor
Secondary search of the ground floor
Removal of hose and exit building.

Subject 45:

Initial search with hose from ground to top of third floor
70-kg dummy removed from third floor and dragged to ground floor
Walk up to the third floor
Drag hose to ground floor and exit due to cylinder change

Figure 3.8: Firefighters performing a structural search (left) and rescue (right) in ambient conditions as part of the second simulation of the hot-cell structural search and rescue. These conditions allowed for the analysis of respiratory measures, collected here by the MetaMax 3B.

Drag 70-kg dummy back up to the third floor

Secondary search of all floors with hose *en route* to ground floor

Removal of hose and exit building.

Subject 46:

Initial search with hose from ground to top of third floor

50-kg dummy removed from third floor and dragged to ground floor

Walk back up to the third floor

70-kg dummy removed from third floor and dragged to ground floor

Secondary search of all floors with hose *en route* to ground floor

Removal of hose and exit building.

Subject 47:

Initial search of ground floor

Drag 50-kg dummy up to the third floor

Walk down to ground floor

Drag 70-kg dummy up to the third floor

Drag hose up to the third floor

50-kg dummy removed from third floor and dragged to ground floor

Ground floor secondary search and exit building.

Subject 48:

Initial search with hose from ground to top of third floor

70-kg dummy removed from third floor and dragged to first floor.

Walk down to ground floor, secondary search and exit building.

Subject 49:

Initial search of the ground and first floors

Drag 70-kg dummy from the first to the third floors

Drag hose from third floor to ground floor and remove hose from building

Walk up to the second and third floors and conduct final search

Return to ground floor and exit from building.

Subject 50:

Initial search from the ground to the third floors

70-kg dummy removed from third floor and dragged to ground floor

Drag 50-kg dummy from the ground floor to the second floor

Walk down to the ground floor

Drag hose to the third floor

Walk down to ground floor and remove 70-kg dummy from building

Final search of all floors, return to ground floor and exit from building.

Subject 51:

Initial search of the ground floor

Drag 70-kg dummy to the second floor

Search of the second and third floors

Return to the ground floor and exit from building.

3.2.5 Experimental standardisation

Testing for each firefighter was conducted using euhydrated subjects. Subjects were asked to refrain from strenuous exercise and the consumption of alcohol and tobacco during the 12 h prior to each trial. It becomes necessary to control hydration levels, given cardiorespiratory variables are affected by hydration status (Saltin, 1964; Goulet *et al.*, 2008). Subjects were also instructed to drink 15 $mL.kg^{-1}$ of additional water in the evening before testing (1.125 L for a 75-kg person), and to eat an evening meal and breakfast high in carbohydrate and low in fat. In the morning, subjects were required to drink 500 mL of fluid (in any form) with breakfast. For the hot-cell structural search and rescue, subjects provided a urine sample on arrival, to check hydration state, and were immediately provided with supplementary water (10 $mL.kg^{-1}$; 750 mL for a 75-kg person) if not adequately hydrated (urine specific gravity not < 1.020; Armstrong *et al.*, 1994).

3.2.6 Data collection procedures

During these trials, the following physiological measures were recorded: heart rate, oxygen consumption and minute ventilation. In addition to this, body core temperature was measured for the hot-cell structural search and rescue. Psychophysical measurements were also collected for all simulations.

3.2.6.1 Physiological measures

Cardiac frequency

Heart rate was monitored continuously from ventricular depolarisation via Polar T31 heart rate monitors (15-s intervals; Polar Electro Sports Tester, Finland).

Oxygen consumption, minute ventilation, carbon dioxide production

Expired air was analysed continuously using a portable, open-circuit, expired gas analysis and ventilation system (5-s intervals; Metamax 3B, Cortex Biophysik, Leipzig, Germany; Figure 3.9) and was worn with the full personal protective ensemble. Figure 3.9 further illustrates the separate parts of the MetaMax 3B system. This involved separate determination of minute ventilation (turbine), tidal volume, breathing frequency, expired oxygen (electro chemical cell), and carbon dioxide concentrations (infra-red). The analysers were calibrated for gas (alpha gas standards; 15.97% oxygen, 4.03% carbon dioxide, balance nitrogen), pressure (barometer) and volume (M9474-C, 3000mL calibration syringe, Hans Rudolph Inc., Kansas City, U.S.A.) prior to each task.

Minute ventilation for the hot-fire cell

A first-principles approximation of minute ventilation was also derived for work completed within the hot-fire cell. This was necessary, as calculating metabolic demand in live-fire situations can damage the open-circuit, expired gas analysis and ventilation systems. Thus, total air use was computed from the change in air cylinder pressure over the duration of the simulation. Cylinder pressures at identical surface temperatures were determined by Breathing Apparatus Training personnel from Fire & Rescue NSW. Minute ventilation was derived from the equation:

Minute ventilation [L.min^{-1}] = ((initial pressure * cylinder volume) - (final pressure * cylinder volume)) / time [min]

Note: cylinder volume = 6.8 L.

Body core temperature

During the hot-fire cell simulations that involved heat and smoke, core temperature was approximated using gastrointestinal temperatures, and recorded continuously using a radio

Figure 3.9: Clockwise from top left: The open-circuit, expired gas analysis and ventilation system battery (MetaMax 3B); left unit of the MetaMax 3B incasing the electro chemical cell (to measure expired oxygen) and infra-red capsule (to measure carbon dioxide concentrations); outer-turbine casing; turbine (to measure minute ventilation).

pill (Jonah 500-0100-02, Respironics Deutschland, Herrsching, Germany; mass = 1.6 g; size = 8.7 mm diameter * 23 mm length) ingested 60 min prior to each trial. Data were sampled at 1-min intervals (VitalSense, Mini Mitter Co. Inc, OR, U.S.A.; mass = 200 g; size = 120 mm * 90 mm * 45 mm), with sampling activated immediately. The pills were swallowed with 37°C water and subjects started soon after. This method of measuring core temperature has been validated in the previous literature during routine daily activities (McKenzie and Osgood, 2004), and intermittent exercise of varying intensities (Gant *et al.*, 2006).

3.2.6.2 Psychophysical measures

Perceived exertion

Perceived exertion ratings (RPE) were obtained during the trade tasks using the 15-point Borg Scale, after being asked: "How hard are you exercising" (6-20: 6 = very, very light, and 20 = maximal exertion; Borg, 1962a). These ratings were recorded ever 3 min, unless the simulation duration was less than 3 min. In this case, ratings were recorded once the simulation was complete.

The 15-point Borg scale

6	
7	Extremely light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal Exertion

3.2.7 Data analysis

Oxygen consumption data were reported in three measures, both absolute ($L.min^{-1}$) and two relative normalisation procedures. Of the relative measures, the first was a linear mass normalisation ($mL.kg^{-1}.min^{-1}$) using body mass at rest and total mass (body, clothing and all protective equipment) during each simulation. Indeed, exercising oxygen consumption has been shown to correlate better with body mass than surface area (Seltzer, 1940) and is hence often normalised to body mass when quantifying physically demanding occupations (Gledhill and Jamnik 1992a). This normalisation is based upon a linear assumption. For the analysis of different body sizes, this assumes that dividing a person's mass into the respective absolute oxygen consumption will always permit the comparison between the relative impact of a exercise stimulus upon different people. Thus, the effect of body mass is believed to be removed.

However, the use of this linear normalisation is fraught with mis-interpretation, and is often inappropriate. For instance, the relationship between oxygen consumption and body mass may not always occur linearly (Kleiber, 1932; Tanner, 1949; Åstrand and Rodahl, 1986; Nevill *et al.*, 1992), and inter-individual variability in oxygen consumption is not accounted for when using such a relationship (Kleiber, 1947). Furthermore, negative relationships can exist between body mass and peak specific oxygen consumption ($mL.kg^{-1}.min^{-1}$) when quantifying maximal aerobic power (Taylor *et al.*, 1981; Schmidt-Nielsen, 1984). This is due to the overcompensation for body mass, and such instances can lead to invalid associations regarding physical performance (Heil, 1997; Vanderburgh and Batterham, 1999). Indeed, this over-compensation can disadvantage aerobic scores of heavier individuals (Vanderburgh and Mahar, 1995; Dooman and Vanderburgh, 2000; Vanderburgh, 2008). This is partly due to the known, directly proportional relationship between muscular strength and muscle cross sectional area, and peak oxygen consumption and blood vessel cross sectional area (Åstrand and Rodahl, 1986).

Therefore, alternative methods of normalising for body mass were utilised in this investigation. It is well known that body mass and oxygen consumption possess a power relationship at rest (Kleiber, 1932; Schmidt-Nielsen, 1984), and across metabolic states through to maximal exercise (Taylor *et al.* 1981; Åstrand and Rodahl, 1986). Thus, whilst individual size is important, it is appropriate that oxygen consumption be derived from a power scaling function, rather than a linear function. This allowed us to compare the oxygen consumption of individuals of different sizes (independent of mass). The relative expression utilised in this study was normalised to the 0.67 power of either nude body mass (rest) or total body mass including the weight of the personal protective ensemble ($mL.kg^{-0.67}.min^{-1}$). Data presented in this manner meant the variations in subject mass and size (Table 3.1) were not responsible for results of the specific oxygen cost of the simulations performed. Since legally defensible screening tests are designed to identify those with the physical and physiological attributes required to perform the job in a safe and efficient manner, this was a critical and necessary part of this occupational task assessment.

Time-series heart rate and oxygen consumption data from each individual, and within each simulation, were analysed with respect to zones of physiological strain. For cardiovascular strain, these zones were defined relative to each individual's heart rate reserve, defined as follows:

> Heart rate reserve = predicted maximal heart rate - resting heart rate [beats.min^{-1}] where: predicted maximal heart rate = 208 - age * 0.7 [beats.min^{-1}] after: Tanaka *et al.* (2001) resting heart rate = mean over last 2 min of a 5-min seated rest [beats.min^{-1}].

Strain thresholds were set at 25%, 50%, 75%, 90% and >90% of the heart rate reserve. While arbitrary thresholds, this allowed for an approximate evaluation of exercise intensity and allows for the comparison of intensities across the literature. Indeed, when recording heart rate, these values can be misinterpreted to indicate that a significant or insignificant portion of the simulation was performed at a particular intensity. For example, if maximal heart rate for a one minute simulation was recorded at 180 beats.min^{-1}, this would indicate the simulation was performed at a high intensity. However, this value may be significantly greater than mean heart rate and may have occurred only once during the simulation, giving a poor indication of the overall cardiovascular strain of the task. Thus, these strain threshold illustrations will show the times spent within zones of different physiological strain during the simulation. This general approach in quantifying cardiac strain to identify and rank stressful trade tasks has been recommended by previous researchers (Taylor and Groeller, 2003). However, multi-layered garments, such as those worn by contemporary firefighters, trap heat (Nunneley, 1989; McLellan, 2008) increasing heart rate out of proportion to metabolic demand. Thus, in addition to heart rate, physiological strain was also evaluated from oxygen uptake data. Therefore, oxygen uptake zones were set at increments of 0.5 $L.min^{-1}$ over the range 1.0-3.0 $L.min^{-1}$. To further evaluate central cardiovascular strain, both the cardiovascular impulse and load were derived for each of the simulations. These were defined as:

Cardiovascular impulse = task duration * average heart rate [beats]

Cardiovascular load = average task heart rate / resting heart rate * duration [non-dimensional units].

Data in this study were analysed using descriptive statistical procedures to provide a quantitative summary of all measures and observations, and are reported as means (averages), standard deviations (SD) and response ranges. To adequately analyse each simulation, task assessments were also conducted. This process involved classifying fitness, muscular movement and postural positions. Identifying and evaluating various task attributes are inherently the most complex aspects of a task analysis, as these may be assessed in both a subjective and objective manner (Taylor and Groeller, 2003). Taylor and Groeller (2003) recommend a two-tiered approach be utilised in detailed job analyses, incorporating physiological measurements (*e.g.* cardiovascular strain; objective evaluations of work) and task assessment classifications (*e.g.* physical fitness attributes; subjective evaluations). Combining these assessments facilitates an understanding of the most stressful tasks and forms the basis from which a task specific screening test can be based (Payne and Harvey, 2010). Indeed, this is the purpose of this dissertation, and supports the approach utilised within the methods of this Chapter.

For this approach to be conducted whilst maintaining the integrity of the process, fitness classifications were thus defined. These classifications were also derived from an analysis of the task duration, heart rate and oxygen cost (Taylor *et al.,* 2000; Taylor and Groeller, 2003). Strength was defined as the ability of the muscles to exert force to complete the task (Taylor *et al.,* 2000). Muscular endurance was defined as the ability of the muscles to exert force for a sustained period to complete the task (Taylor *et al.,* 2000). Power was defined as the ability of the muscles to exert a contractile force at high velocities (Taylor *et al.,* 2000).

The fitness classifications essential to each occupational task were categorised into primary, secondary and (if necessary) tertiary components. Though subjective, these classifications were also derived from physiological data (Taylor *et al.,* 2000; Taylor and Groeller, 2003), and were established in collaboration with the sound scientific expertise of the Research Team. This process also entailed the evaluation of loads. The loads involved with each task were obtained from detailed Fire & Rescue NSW equipment fact sheets (Rescue Operators Training Manual, 2006). A comprehensive movement analysis was conducted for the muscular actions and muscle groups used within each task. In addition, the author and members of the Research Team conducted video and photography analyses sessions to assist with this process. This process also helped identify the mode of carriage (unilateral or bilateral), the position of the load (with regard to the human body) and the percentage of task time within each position. Previous authors have undertaken similar subjective task assessment procedures (Gledhill and Jamnik, 1992a; Rayson *et al.,* 1998; Taylor *et al.,* 2000; Jamnik *et al.,* 2010b). This analysis permits the evaluation of the affect of occupational equipment on the individual, in addition to providing crucial information with regards to how the task is performed, and what attributes are required for successful task performance (Rayson *et al.,* 2000; Taylor and Groeller, 2003; Payne and Harvey, 2010).

Whilst the subjective nature of this process is recognised, it is argued that through careful observation and expertise, this a scientifically-justified assessment (Taylor and Groeller, 2003). Furthermore, it is most improbable the development of physiological employment standards can take place without any subjective decisions (Tipton *et al.,* 2012), as subjective methods are sometimes more appropriate for physically demanding occupations (Larsen and Aisbett, 2012). Furthermore, the results of these task assessment procedures were independently verified by subject-matter experts from Fire & Rescue NSW, a crucial step when developing physiological emolument standards (Truxillo *et al.,* 2004; Payne and Harvey, 2010). The inclusion of these task assessments, in addition to the physiological measures collected, provide for a thorough and detailed task analysis (Payne and Harvey, 2010). Notwithstanding this, it is clear (and acknowledged by this author) future research must focus on removing some of the subjective components of physiological employment standard development (Tipton *et al.,* 2012), or at the very least strive to assess the reliability and validity of subjective task domain measures with regard to physically demanding occupations (Larsen and Aisbett, 2012).

3.2.8 The distillation of occupational simulations

Analysis of the results in this study assisted in our endeavour to derive a sub-set of tasks that may be useful in the creation of a screening test. This test would represent various levels of physiological strain when performed by operational firefighters with a wide range of experience and skill levels. However, administering a screening test comprising of fifteen fire-fighting simulations, one of which was designed to last 52 minutes in duration, would not be viable (personal communication, Fire & Rescue, NSW). Thus, the Research Team were able to compare the physical and physiological attribute similarities between the results of all fire-fighting simulations.

For instance, consider task A and B. If task A and B entailed similar muscular actions, movements and external loads, but task B required a higher aerobic demand than task A, then the easier task (task A) could be eliminated. Thus, firefighters who can complete task B, would theoretically be able to perform task A. These efficiency gains benefited the next study of this project, which centred upon the development of physiological screening tests for possible use within recruiting. Therefore, a filtration process (Figure 3.10) through which some activities could be culled to minimise the duplication of movement patterns and loads within this sub-set of tasks was developed.

A decision-analysis approach was adopted (Howard, 1966) to fulfill the aims of this filtration process, and a flow chart (Figure 3.10) was developed through which each occupational task was evaluated. This type of approach focusses on incorporating and balancing the numerous factors which effect a decision. Our flow chart firstly separated strength and endurance activities. Simulations involving loads less than 10 kg were excluded unless it was a critical task (Fire & Rescue NSW). If the load was greater than 10 kg proceeding steps within strength-related activities resulted in the classification of tasks

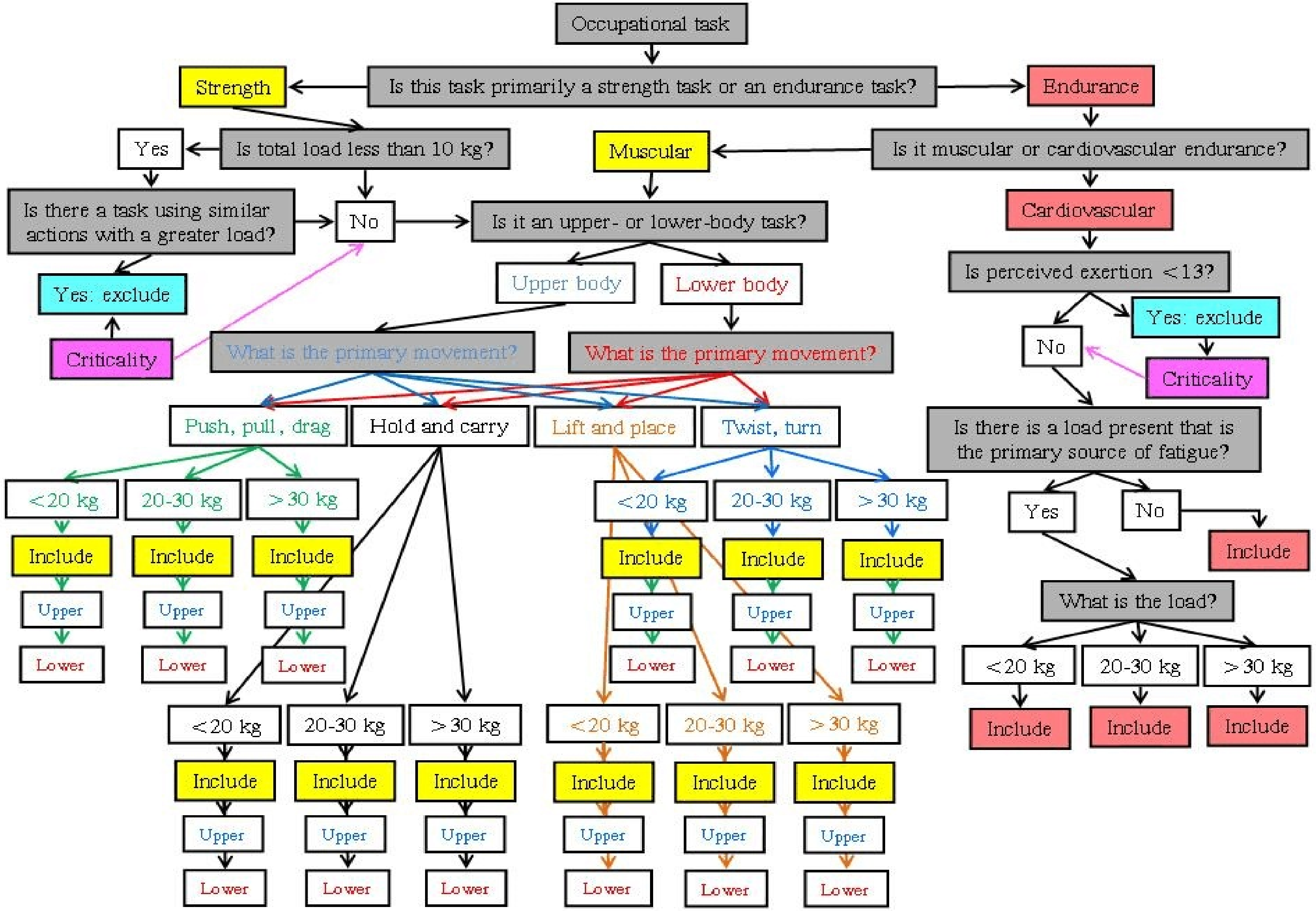

Figure 3.10: A flow chart for the distillation of simulation tasks to minimise the duplication of movement patterns and loads.

according to the body region involved (upper or lower). The primary movements performed were then identified, and were split into four categories: i) push, pull, drag; This will assist in the development of activities that reflect the most meaningful levels of physiological strain. ii) hold and carry; iii) lift and place; iv) twist, turn (adapted from Rayson *et al.,* 19988; Taylor *et al.*, 2000). Finally, the loads carried were compared from three categories: <20 kg, 20-30 kg and > 30 kg.

Steps within endurance-related activities were sub-divided into cardiovascular and muscular endurance activities, the latter which followed the same process as aforementioned from the classification of tasks according to the body region involved (upper or lower). Cardiovascular tasks were firstly split into task with rating of perceived exertions greater or less than 13, the latter of which justified exclusion unless the task was critical (Fire & Rescue NSW). The threshold of 13 was chosen to identify cardiovascular tasks that were perceived by firefighters to be "somewhat hard" (Borg 1962a and b), and thus eliminate 'easier' cardiovascular tasks to improve test efficiency (personal communication, Fire & Rescue NSW). Cardiovascular tasks were also sub-divided on the basis of load carriage. It is acknowledged here that limitations may exist within various components of this filtration approach. This is not uncommon given the subjective nature of such techniques (Tipton *et al.,* 2012). For instance, it is possible tasks could be wrongfully excluded due to difference in perceptions of task difficulty/effort. Furthermore, there may exist a task with similar actions to another task and possess a lower load (thus recommended for exclusion; Figure 3.10), yet the task may also ascertain additional unique postures required for successful completion. However, tasks were only excluded following confirmation of task criticality from the subject matter experts within the Management Team, alleviating the majority of the possible limitations that may exist within this approach.

3.3 RESULTS

This section has also been sub-divided into the fifteen discrete fire-fighting simulations plus one hot-cell rescue. Physiological strain, overall task assessments and box plot figures are presented separately and all simulations are presented in the order established in the Methods section. However, a more detailed explanation is given, including the presentation format, the descriptive statistics and the graphical procedures that have been used for each simulation and the respective Tables using the Hazmat simulation as an example. For the reader's convenience, the majority of Figures and example experimental data are provided in the Appendices.

<u>3.3.1 Simulation one: Hazmat incident as an example</u>

3.3.1.1 Example experimental data

Physiological strain during the hazmat simulation is illustrated within data for heart rate (Figure 3.11), absolute oxygen consumption (Figure 3.12) and ventilatory responses (Figure 3.13) of one representative firefighter (Subject 4). Within each graph, the coloured bands define zones of increasing physiological strain as one moves (over time) from the lower left to the upper right corner of each Figure.

3.3.1.2 Example physiological and psychophysical strain

Using data collected from every subject during this fire-fighting simulation, Table 3.4 was constructed to summarise the physiological strain experienced during the hazmat simulation. Within this Table five physiological variables are presented: heart rate, oxygen consumption in absolute and specific terms for exercise (mL.kg (total mass of body and equipment)$^{-1}$.min^{-1}; mL. kg [total mass of body and equipment]$^{-0.67}$.min^{-1})) and rest (mL.kg (body mass)$^{-1}$.min^{-1}; mL. kg [body mass]$^{-0.67}$.min^{-1})), tidal volume, minute ventilation and breathing frequency. Average data are presented for the resting and simulation states. The basal data were reflective of the resting values for normal healthy adults. This assumes that any observed differences in the experimental data during the simulation would be attributed to normal physiological function, as influenced by the various functions of the simulation (*e.g.* external load, exercise intensity). Minimal and maximal range parameters define the lower and upper boundaries of physiological strain observed during the simulation. The 95% confidence interval indicates that one can be 95% certain in the assumption that the true average strain for firefighters may be located within the range defined by the mean (*e.g.* heart rate: 133 beats.min^{-1}) minus the confidence interval (7 beats.min^{-1}), and the mean plus that confidence interval. Thus, for the hazmat incident, the true simulation mean has a 95% probability of falling between the heart rates of 126 to 140 beats.min^{-1}. Mean

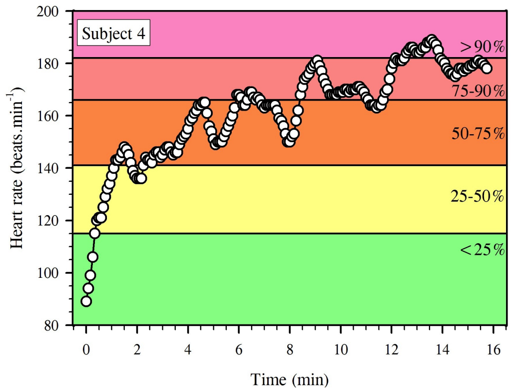

Figure 3.11: Example heart rate response during the hazmat simulation.

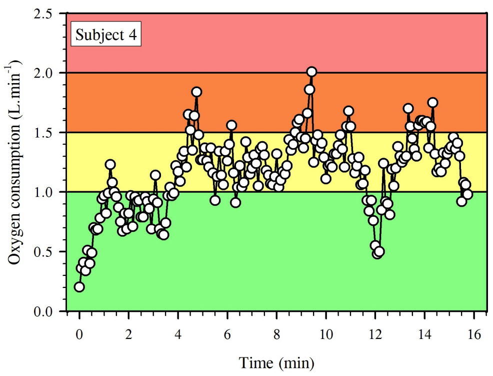

Figure 3.12: Example oxygen consumption response during the hazmat simulation.

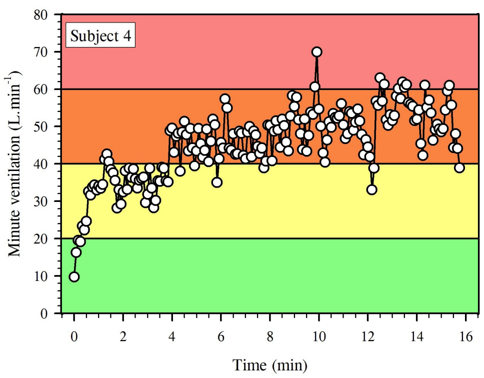

Figure 3.13: Example ventilatory response during the hazmat simulation.

Table 3.4: Summary parameters for physiological strain in firefighters (N=16) performing the hazmat incident simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	79 (10)	133 (13)	82	189	7
Absolute oxygen consumption (L.min^{-1})	0.32 (0.08)	1.61 (0.29)	0.30	3.36	0.14
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.47 (0.62)	13.96 (2.21)	2.73	28.45	1.08
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	15.45 (2.90)	66.79 (10.66)	12.89	134.92	5.22
Minute ventilation (L.min^{-1})	15.70 (3.60)	57.44 (6.91)	14.47	94.97	3.39
Tidal volume (L)	0.93 (0.31)	1.80 (0.32)	0.48	3.22	0.16
Breathing frequency (breaths.min^{-1})	19 (6)	33 (5)	9	61	2

absolute oxygen consumption will lie within the zone ranging from 1.47 to 1.75 $L.min^{-1}$.

Figure 3.14 illustrates box plot summaries of heart rate and absolute oxygen consumption data. Work rate intensities are for work performed across the entire hazmat simulation. However, these times are not displayed chronologically, but are drawn from different parts of, or from different times within this simulation. Within each box, five pieces of descriptive information are provided concerning the simulation.

- the upper box border is the 75^{th} percentile: 75% of times were below this line
- the upper error bar defines the 95^{th} percentile
- the lower box border is the 25^{th} percentile: 75% of times were above this line
- the lower error bar defines the 5^{th} percentile.
- the horizontal line within each box is the median time spent within each strain zone.

These data (reflections of work rate intensity) complement the summaries of physiological strain (*e.g.* Table 3.4). Within these box plot analyses, the variation in medians across the zones of physiological strain highlight the different times spent within each zone. These data give an additional appreciation for the physiological demands of each occupational task. For instance, measures of various physiological variables may in some cases give an inappropriate indication of the physiological strain of the task. This is especially critical for tasks with short durations, whereby an approximate steady state will not be reached (Sheppard *et al.,* 1968; Nielson *et al.*, 2010). For example, a maximal oxygen consumption of 4 $L.min^{-1}$ for a given task would indicate a high level of physiological strain, but provide no indication of the likely impact of this work rate over the entire time period of the simulation. Thus, it was deemed appropriate to investigate data within the different times of each simulation to provide additional information when quantifying the physiological demands of each task. Such analyses are further examples of the detailed job analyses conducted throughout this investigation, a critical component in developing legally defensible physiological employment standards (Payne and Harvey, 2010).

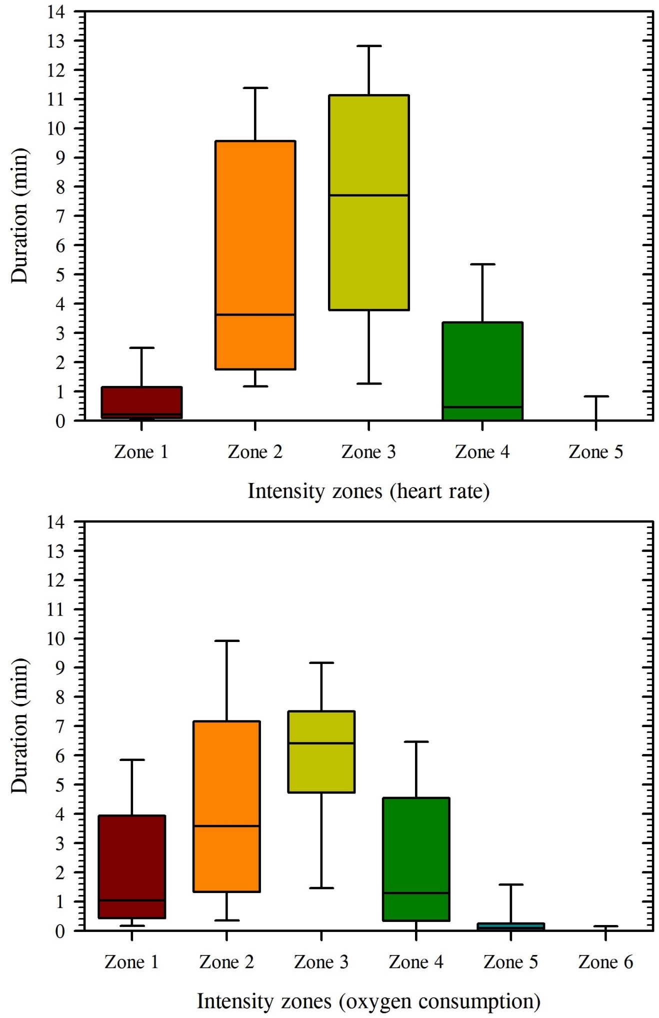

Figure 3.14: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the hazmat incident simulation. Zone thresholds (1-5) were set at 25%, 50%, 75%, 90% and >90% of the heart rate reserve (scope), and at increments (zones 1 to 6) of 0.5 $L.min^{-1}$ over the absolute oxygen consumption range 1.0-3.0 $L.min^{-1}$. The lower border of each box shows the 25th percentile, the line within the box is the median and the upper border is the 75th percentile. The error bars above and below each box define the 95th and the 5th percentiles.

The information given in Table 3.4 must be carefully considered when assessing the likely physiological impact of the different work rates. For instance, no temporal information is gained concerning the observed maximal oxygen consumption of 3.36 L.min^{-1}. This is a very high work intensity (zone 6; Figure 3.14), and it could be misinterpreted to indicate that a significant proportion of the simulation, which lasted 15.24 min, was performed working at this intensity. However, the duration spent in this zone (6) (>3.0 L.min^{-1}) was very brief (1.8 sec). Therefore, oxygen consumption data for this zone (6) can be ignored, as it is too brief to represent a significant physiological demand.

3.3.2 Physiological strain for all fire-fighting simulations

Physiological strain during the fifteen simulations is summarised in Tables 3.5 to 3.22. Table 3.23 provides mean physiological data across all fifteen fire-fighting simulations. Five physiological variables are presented: heart rate, oxygen consumption, tidal volume, minute ventilation and breathing frequency.

3.3.2.1 Cardiac frequency

Cardiac frequency can give an indication of the cardiovascular strain endured in these tasks. Mean heart rates across all fifteen occupational simulation ranged from 113 beats.min^{-1} to 165 beats.min^{-1}. One-third of the tasks (firefighter rescue, stair climb with charged 38-mm hose, stair climb with ventilation fan, ladder use and the use of a sledge axe to gain entry) entailed considerable cardiovascular strain, recording mean heart rates of 155 beats.min^{-1} or higher. The results for each simulation were most likely a function of the type of activity and the intensity at which the task was performed. For instance, whilst the ventilation fan carry task was short in duration (1.51 min), it was performed at a high, continuous intensity and reached mean heart rate values of 157 beats.min^{-1} (SD 11; Table 3.23). Furthermore, the firefighter rescue task in this study involved dragging a fully clothed and protected firefighter to safety (106.57 kg) and reported a mean heart rate of 161 beats.min^{-1} (SD 16; Table 3.23). The use of a sledge axe elicited the highest mean heart rate (165 beats.min^{-1} (SD 13; Table 3.23)). Given this task was representative of a forced entry to save life, it was performed as rapidly, yet safely, as possible and this is reflected across all data for this simulation.

Table 3.5: Summary parameters for physiological strain in firefighters ($N=16$) performing a motor-vehicle rescue simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	78 (15)	127 (17)	88	192	8
Absolute oxygen consumption (L.min^{-1})	0.34 (0.11)	1.25 (0.21)	0.26	2.84	0.10
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.72 (1.15)	11.07 (1.68)	2.28	24.85	0.82
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.51 (4.99)	52.50 (7.91)	10.89	118.56	3.88
Minute ventilation (L.min^{-1})	16.14 (3.24)	47.52 (9.67)	15.76	114.23	4.74
Tidal volume (L)	0.78 (0.12)	1.44 (0.23)	0.43	2.89	0.11
Breathing frequency (breaths.min^{-1})	21 (4)	34 (5)	14	79	2

Table 3.6: Summary parameters for physiological strain in firefighters (N=16) performing a hose roll-out (70 mm) simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (11)	144 (13)	88	175	6
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	1.58 (0.36)	0.22	3.02	0.17
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	15.21 (3.45)	2.12	32.27	1.69
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.94 (5.21)	70.27 (15.43)	9.82	144.31	7.56
Minute ventilation (L.min^{-1})	18.15 (5.21)	47.62 (14.58)	9.84	125.44	7.14
Tidal volume (L)	0.90 (0.22)	1.61 (0.29)	0.41	3.18	0.14
Breathing frequency (breaths.min^{-1})	21 (4)	30 (7)	10	57	3

Table 3.7: Summary parameters for physiological strain in firefighters ($N=16$) performing a hose-coupling simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (11)	135 (13)	98	165	7
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	1.40 (0.31)	0.33	2.59	0.15
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	13.49 (2.87)	2.88	23.33	1.41
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.94 (5.21)	62.39 (12.95)	13.76	106.22	6.34
Minute ventilation (L.min^{-1})	18.15 (5.21)	49.57 (13.46)	14.19	119.55	6.60
Tidal volume (L)	0.90 (0.22)	1.72 (0.34)	0.75	2.76	0.17
Breathing frequency (breaths.min^{-1})	21 (4)	29 (6)	12	52	3

Table 3.8: Summary parameters for physiological strain in firefighters ($N=16$) performing a hydrant connection simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (11)	150 (17)	86	186	8
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	1.56 (0.39)	0.29	3.21	0.19
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	14.95 (3.56)	2.80	31.77	1.75
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.94 (5.21)	69.14 (16.18)	12.94	145.71	7.93
Minute ventilation (L.min^{-1})	18.15 (5.21)	58.55 (16.88)	17.44	127.24	8.27
Tidal volume (L)	0.90 (0.22)	1.83 (0.42)	0.62	3.19	0.20
Breathing frequency (breaths.min^{-1})	21 (4)	32 (6)	17	58	3

Table 3.9: Summary parameters for physiological strain in firefighters (N=16) moving a charged 70-mm hose (laterally). Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (12)	136 (18)	105	172	9
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	0.83 (0.23)	0.24	2.15	0.11
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	7.98 (2.37)	2.44	22.44	1.16
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.94 (5.21)	36.83 (10.51)	11.67	100.35	5.15
Minute ventilation (L.min^{-1})	18.15 (5.21)	34.04 (9.31)	13.05	78.88	4.56
Tidal volume (L)	0.90 (0.22)	1.27 (0.28)	0.45	2.32	0.14
Breathing frequency (breaths.min^{-1})	21 (4)	27 (5)	14	53	3

Table 3.10: Summary parameters for physiological strain in firefighters ($N=16$) performing the fire-attack simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (12)	143 (17)	91	189	8
Absolute oxygen consumption (L.min^{-1})	0.36 (0.11)	1.53 (0.38)	0.28	3.01	0.19
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	14.76 (3.75)	3.18	29.38	1.84
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.94 (5.21)	68.19 (16.84)	15.16	134.85	8.25
Minute ventilation (L.min^{-1})	18.15 (5.21)	58.21 (13.53)	14.23	116.05	6.63
Tidal volume (L)	0.90 (0.22)	1.61 (0.36)	0.35	3.23	0.18
Breathing frequency (breaths.min^{-1})	21 (4)	37 (6)	18	60	3

Table 3.11: Summary parameters for physiological strain in firefighters (N=16) performing a one-person firefighter rescue. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (12)	161 (16)	97	188	8
Absolute oxygen consumption (L.min^{-1})	0.36 (0.12)	1.68 (0.46)	0.32	2.90	0.24
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.45 (1.20)	16.22 (4.58)	2.84	28.20	2.40
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	18.79 (5.57)	67.91 (17.92)	10.01	129.92	9.39
Minute ventilation (L.min^{-1})	18.15 (5.21)	70.22 (14.10)	26.64	116.62	6.91
Tidal volume (L)	0.90 (0.22)	1.84 (0.42)	0.60	3.67	0.21
Breathing frequency (breaths.min^{-1})	21 (4)	39 (5)	24	71	2

Table 3.12: Summary parameters for physiological strain in firefighters (N=16) performing a bushfire (hose-drag) simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	91 (11)	143 (15)	77	189	8
Absolute oxygen consumption (L.min^{-1})	0.37 (0.11)	1.63 (0.44)	0.23	3.83	0.22
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	4.52 (1.09)	18.10 (4.23)	2.98	44.40	2.07
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	19.21 (4.84)	79.69 (19.08)	12.51	193.28	9.35
Minute ventilation (L.min^{-1})	17.81 (5.34)	58.65 (12.64)	12.91	127.96	6.19
Tidal volume (L)	0.93 (0.22)	1.70 (0.32)	0.47	3.89	0.16
Breathing frequency (breaths.min^{-1})	20 (4)	35 (4)	13	79	2

Table 3.13: Summary parameters for physiological strain in firefighters ($N=17$) performing a stair climb, dragging a charged 38-mm hose (leading firefighter). Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	79 (10)	156 (15)	95	188	7
Absolute oxygen consumption (L.min^{-1})	0.33 (0.11)	1.97 (0.61)	0.43	4.03	0.29
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.79 (1.26)	17.81 (5.04)	3.80	33.90	2.40
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.46 (5.40)	84.04 (23.84)	18.10	163.91	11.33
Minute ventilation (L.min^{-1})	17.12 (5.78)	81.99 (16.11)	18.79	138.93	7.66
Tidal volume (L)	0.82 (0.18)	2.02 (0.35)	0.63	3.34	0.17
Breathing frequency (breaths.min^{-1})	21 (6)	41 (6)	21	65	3

Table 3.14: Summary parameters for physiological strain in firefighters ($N=17$) performing a stair climb, dragging a charged 38-mm hose (support firefighter). Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	78 (10)	158 (14)	82	190	7
Absolute oxygen consumption (L.min^{-1})	0.32 (0.11)	1.84 (0.68)	0.20	3.94	0.32
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.74 (1.23)	16.78 (6.00)	1.77	31.88	2.85
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.26 (5.35)	78.97 (28.07)	8.42	154.13	13.34
Minute ventilation (L.min^{-1})	16.87 (6.04)	83.79 (15.80)	16.66	134.94	7.51
Tidal volume (L)	0.82 (0.19)	2.07 (0.41)	0.57	3.87	0.19
Breathing frequency (breaths.min^{-1})	21 (6)	41 (6)	20	64	3

Table 3.15: Summary parameters for physiological strain in firefighters ($N=14$) using a 38-mm hose for a prolonged duration. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	113 (20)	74	172	11
Absolute oxygen consumption (L.min^{-1})	0.33 (0.12)	0.55 (0.17)	0.13	2.26	0.09
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.76 (1.28)	4.92 (1.40)	1.15	16.47	0.74
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.45 (5.88)	23.30 (6.59)	5.47	83.56	3.45
Minute ventilation (L.min^{-1})	17.53 (6.31)	26.30 (5.12)	10.64	66.41	2.68
Tidal volume (L)	0.83 (0.18)	0.91 (0.14)	0.37	2.35	0.07
Breathing frequency (breaths.min^{-1})	22 (6)	30 (6)	8	68	3

Table 3.16: Summary parameters for physiological strain in firefighters ($N=13$) using a 70-mm hose for a prolonged duration. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	123 (19)	60	157	10
Absolute oxygen consumption (L.min^{-1})	0.34 (0.13)	0.56 (0.13)	0.14	1.51	0.08
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.75 (1.45)	4.94 (1.39)	1.20	13.43	0.79
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.49 (6.32)	23.40 (6.12)	5.76	63.81	3.46
Minute ventilation (L.min^{-1})	17.64 (6.66)	26.45 (5.77)	11.06	59.76	3.14
Tidal volume (L)	0.83 (0.20)	0.88 (0.14)	0.44	2.06	0.08
Breathing frequency (breaths.min^{-1})	22 (6)	31 (5)	14	64	3

Table 3.17: Summary parameters for physiological strain in firefighters (N=15) performing the entire 10.5-m ladder simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	159 (19)	75	198	10
Absolute oxygen consumption (L.min^{-1})	0.33 (0.12)	1.44 (0.46)	0.28	3.47	0.24
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.92 (1.22)	12.95 (3.84)	2.39	28.93	2.01
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.56 (5.34)	61.15 (18.23)	11.52	134.41	9.55
Minute ventilation (L.min^{-1})	17.35 (6.12)	70.48 (12.77)	20.04	122.03	6.46
Tidal volume (L)	0.82 (0.18)	1.80 (0.33)	0.41	3.13	0.16
Breathing frequency (breaths.min^{-1})	22 (6)	40 (4)	19	75	2

Table 3.18: Summary parameters for strain in firefighters (N=15) performing a 10.5-m ladder under-run simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimum	Maximum	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	161 (20)	75	198	10
Absolute oxygen consumption (L.min^{-1})	0.33 (0.12)	1.40 (0.50)	0.28	3.05	0.26
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.92 (1.22)	12.77 (5.06)	1.59	23.93	2.40
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.56 (5.34)	59.90 (21.42)	11.52	128.19	11.22
Minute ventilation (L.min^{-1})	17.35 (6.12)	72.08 (16.77)	25.11	122.03	8.49
Tidal volume (L)	0.82 (0.18)	1.85 (0.40)	0.63	3.13	0.20
Breathing frequency (breaths.min^{-1})	22 (6)	40 (5)	19	65	2

Table 3.19: Summary parameters for physiological strain in firefighters (N=15) performing a 10.5-m ladder ascent simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimum	Maximum	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	161 (27)	75	196	13
Absolute oxygen consumption (L.min^{-1})	0.33 (0.12)	1.66 (0.66)	0.28	3.47	0.35
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.92 (1.22)	14.99 (5.88)	2.39	28.59	3.08
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.56 (5.34)	70.68 (27.41)	11.52	128.30	14.36
Minute ventilation (L.min^{-1})	17.35 (6.12)	76.10 (21.47)	26.26	122.03	10.87
Tidal volume (L)	0.82 (0.18)	1.97 (0.56)	0.69	3.13	0.28
Breathing frequency (breaths.min^{-1})	22 (6)	39 (6)	24	62	3

Table 3.20: Summary parameters for strain in firefighters (N=15) performing a 10.5-m ladder carry and restow simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (11)	169 (11)	112	197	6
Absolute oxygen consumption (L.min^{-1})	0.33 (0.12)	1.48 (0.52)	0.32	2.94	0.27
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.92 (1.22)	14.75 (6.11)	2.43	28.59	3.20
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.56 (5.34)	62.95 (19.98)	12.17	116.38	10.47
Minute ventilation (L.min^{-1})	17.35 (6.12)	70.31 (14.92)	27.79	115.70	7.82
Tidal volume (L)	0.82 (0.18)	2.04 (0.35)	0.75	3.08	0.18
Breathing frequency (breaths.min^{-1})	22 (6)	39 (5)	19	64	3

Table 3.21: Summary parameters for strain in firefighters (N=17) performing a ventilation fan carry simulation (up stairs). Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	80 (12)	157 (11)	99	192	5
Absolute oxygen consumption (L.min^{-1})	0.34 (0.11)	1.49 (0.53)	0.31	3.38	0.26
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.85 (1.23)	13.29 (4.89)	2.61	28.55	2.40
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.86 (5.30)	62.93 (22.60)	12.64	137.82	11.07
Minute ventilation (L.min^{-1})	17.40 (5.86)	76.87 (11.89)	25.11	130.44	5.83
Tidal volume (L)	0.83 (0.19)	1.86 (0.32)	0.64	3.59	0.16
Breathing frequency (breaths.min^{-1})	22 (6)	41 (7)	20	70	3

Table 3.22: Summary parameters for strain in firefighters (N=16) performing a sledge axe forced entry simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	79 (11)	165 (13)	110	196	6
Absolute oxygen consumption (L.min^{-1})	0.35 (0.11)	1.55 (0.35)	0.30	3.37	0.18
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.94 (1.29)	13.95 (3.22)	2.28	28.64	1.69
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	17.13 (5.59)	65.93 (14.49)	11.41	137.41	7.59
Minute ventilation (L.min^{-1})	17.40 (5.86)	82.07 (16.39)	16.12	155.44	8.03
Tidal volume (L)	0.83 (0.19)	1.91 (0.32)	0.40	3.52	0.16
Breathing frequency (breaths.min^{-1})	22 (6)	43 (7)	19	74	3

Table 3.23: Physiological strain while performing the fifteen fire-fighting simulations. Data are means, with additional standard deviations in parenthesis for physiological variables.

Simulation	*n*	Duration (min)	Heart rate (beats.min^{-1})	Absolute oxygen consumption (L.min^{-1})
Simulation 1: Hazmat incident	16	15.24	134 (13)	1.61 (0.29
Simulation 2: Motor-vehicle rescue	16	14.37	127 (17)	1.25 (0.21)
Simulation 3: Rolling out hose (70 mm)	16	1.68	144 (13)	1.58 (0.36)
Simulation 4: Coupling hoses	16	1.14	135 (13)	1.40 (0.31)
Simulation 5: Locating and connecting to hydrant	16	2.78	150 (17)	1.56 (0.39)
Simulation 6: Drag charged 70-mm hose (lateral)	16	7.09	136 (18)	0.83 (0.23)
Simulation 7: Fire attack	16	4.16	143 (17)	1.53 (0.38)
Simulation 8: Firefighter down - rescue	16	3.84	161 (16)	1.68 (0.46)
Simulation 9: Bushfire incident	16	52.33	143 (15)	1.63 (0.44)
Simulation 10: Stair climb dragging charged hose (lead)	17	2.46	156 (17)	1.97 (0.61)
Simulation 11: Prolonged use of hose (38 mm)	14	15.36	113 (20)	0.55 (0.17)
Simulation 12: Prolonged use of hose (70 mm)	13	15.40	123 (19)	0.56 (0.13)
Simulation 13: Ladder use (10.5 m)	15	7.28	159 (19)	1.44 (0.46)
Simulation 14: Stair climb with ventilation fan	17	1.51	157 (11)	1.49 (0.53)
Simulation 15: Use of sledge axe to gain entry	16	2.50	165 (13)	1.55 (0.35)

3.3.2.2 Oxygen consumption

Cardiorespiratory variables give a good overall indication of the metabolic burden of performing the trade task simulations. Mean absolute oxygen consumption across all simulations ranged from 0.55 L.min^{-1} to 1.97 L.min^{-1}. For instance, absolute mean oxygen consumption for the ventilation fan carry task reached 1.49 L.min^{-1} (Table 3.21; with one subject reaching a peak oxygen cost of 3.38 L.min^{-1}). During the most demanding fire-fighting simulation (stair climb with charged 38-mm hose), the mean absolute oxygen consumption was 1.97 L.min^{-1} (SD 0.61; Table 3.23). These data were consistent with significant muscular, cardiovascular (mean heart rate 156 beats.min^{-1} SD 15) and metabolic demand, even though its average duration was 2.46 min. However, some simulations elicited a fairly low physiological demand. For example, both hose-use tasks (prolonged use of hoses: 38 mm and 70 mm) mean oxygen consumption values were 0.55 L.min^{-1} and 0.56 L.min^{-1} (Table 3.23) respectively. These low values are most likely attributable to these tasks being stationary, and were instead reliant on sustained isometric muscular contractions. Tasks involving the rapid climbing of stairs and activities entailing heavy manual-handling characteristics induced higher overall physiological strain than those that did not.

3.3.2.3 Minute ventilation

Physiological strain can also be represented by the product of tidal volume and breathing frequency (minute ventilation) data for all simulations. Mean minute ventilation across all simulations ranged from 26.30 L.min^{-1} to 83.79 L.min^{-1}. Predictably, changes in minute ventilation were similar to changes in mean absolute oxygen consumption across simulations. For example, the stair climb with charged 38-mm hose also ascertained the highest minute ventilation values (support firefighter; 83.79 L.min^{-1} SD 15.80; lead firefighter 81.99 L.min^{-1} SD 16.11; Table 3.13 and 3.14). The increases in minute ventilation in these fire-fighting simulations were predominately a function of the activity performed and the intensity of the simulation. For example, minute ventilation increased in the 10.5-m ladder simulation, leading to peak mean values during the climbing of the ladder (76.10 L.min^{-1} SD 21.47; maximum 122.03 L.min^{-1}; Table 3.17 and 3.19).

3.2.3.4 Illustrations of physiological strain

Figures 3.15 to 3.18 provide temporal information for physiological strain across entire simulations. Of more importance is the median within each box (horizontal lines). This highlights how the position of each line varies across the zones of strain: the highest median reveals the region within which firefighters spent most time during this simulation. These zones (for both heart rate and absolute oxygen consumption) provides information regarding the cardiovascular or metabolic burden placed upon firefighters. For instance, for the motor vehicle rescue, whilst the handling of the heavy tools was undoubtably demanding, it did not impose a particularly heavy cardiovascular or metabolic burden upon the firefighters. Instead, this task would seem to rely more heavily upon muscular endurance and strength than upon cardiovascular endurance.

In comparison, there were tasks (*e.g.* rolling out a 70-mm hose) which did not impose a significant physiological burden on firefighters. For this occupational task, the predominant zone for heart rate was zone three, but the variations for absolute oxygen consumption were equally distributed across zones one to four (Figure 3.15). Therefore, this short-duration activity did not impose a particularly heavy cardiovascular or metabolic burden upon the firefighters. Instead, this task would seem to rely more heavily upon strength, power and skill than upon cardiovascular endurance.

Unlike simulations three (roll out 70-mm hose) and four (coupling hoses), the location and connection of a hydrant showed cardiovascular, metabolic and ventilatory strain progressively rising throughout the simulation. For example, the firefighter (Subject one; Figure 3.15) used to illustrate these responses, entered heart rate zone four (75-90% of the heart rate reserve) whilst the absolute oxygen consumption data averaged more than 2.0 $L.min^{-1}$ for more than 40% of the simulation. Therefore, the successful completion of this task would be heavily dependent upon muscular strength and endurance due to its load-carriage nature, but it would also reply upon cardiovascular endurance. Indeed, certain simulations, such as the bush drag task (Figure 3.12), there was significant reliance upon cardiovascular endurance. Similar characteristics were also present in the fire attack simulation. The most time in this scenario was spent in zones three and four for both heart

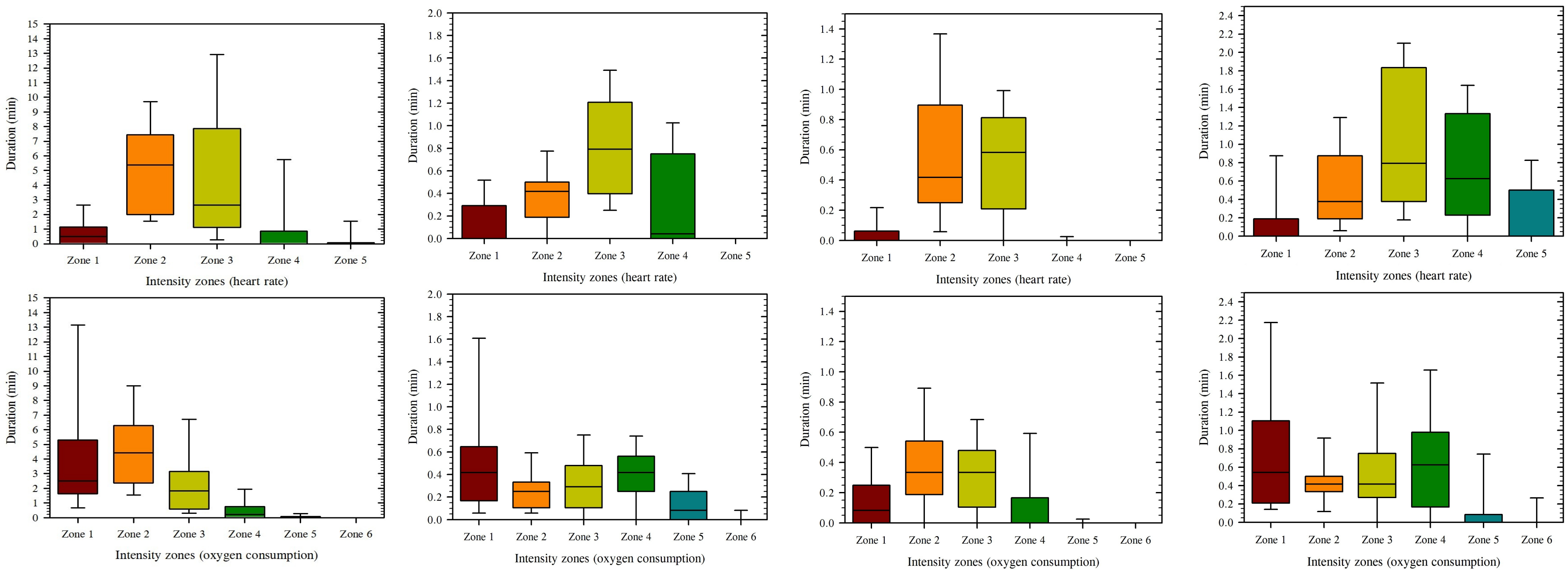

Figure 3.15: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during (top right) the motor-vehicle rescue simulation, bowling 70-mm, coupling hoses, location and connection of a fire hydrant. Zone thresholds were set at 25%, 50%, 75%, 90% and >90% of the heart rate reserve, and at increments of 0.5 $L.min^{-1}$ over the absolute oxygen consumption range 1.0-3.0 $L.min^{-1}$. The lower border of each box shows the 25th percentile, the line within the box is the median and the upper border is the 75th percentile. The error bars above and below each box define the 95th and the 5th percentiles.

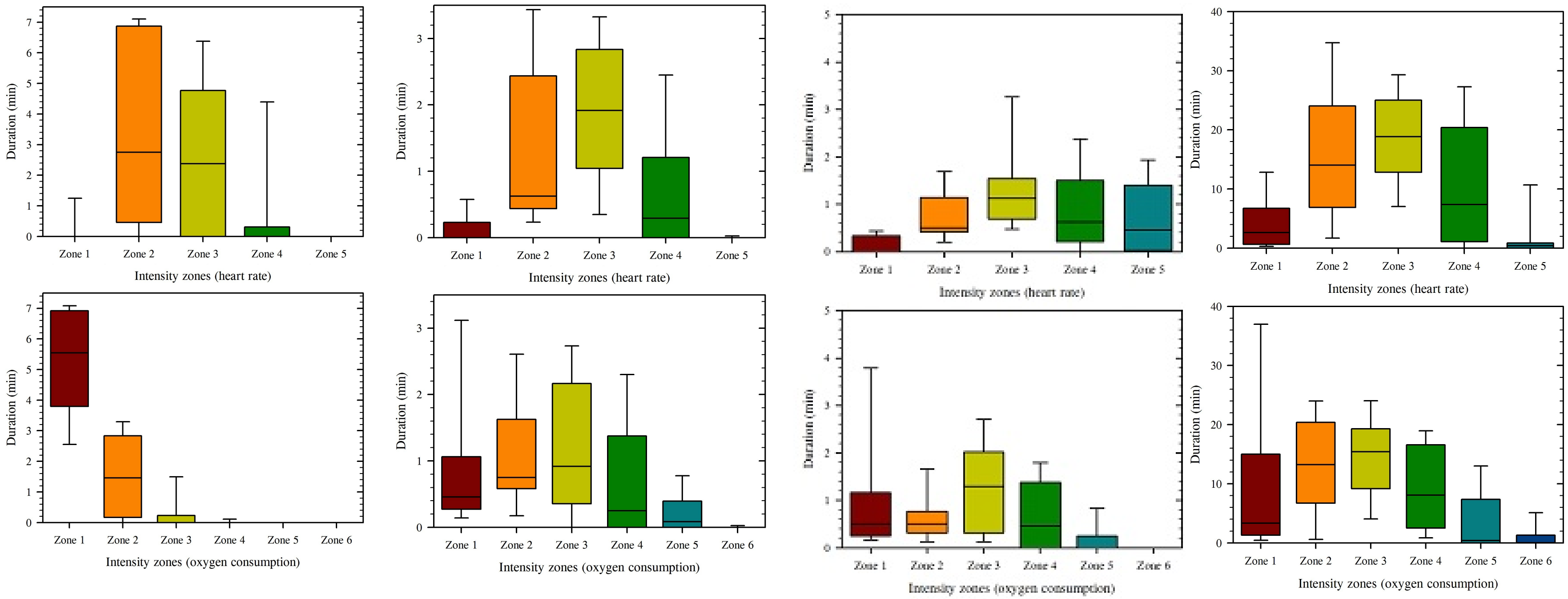

Figure 3.16: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (left to right): dragging a 70-mm hose laterally, fire attack, firefighter rescue, dragging charged 38-mm hose (uneven terrain; bush drag) simulation. Zone thresholds were set at 25%, 50%, 75%, 90% and >90% of the heart rate reserve, and at increments of 0.5 $L.min^{-1}$ over the absolute oxygen consumption range 1.0-3.0 $L.min^{-1}$. The lower border of each box shows the 25th percentile, the line within the box is the median and the upper border is the 75th percentile. The error bars above and below each box define the 95th and the 5th percentiles.

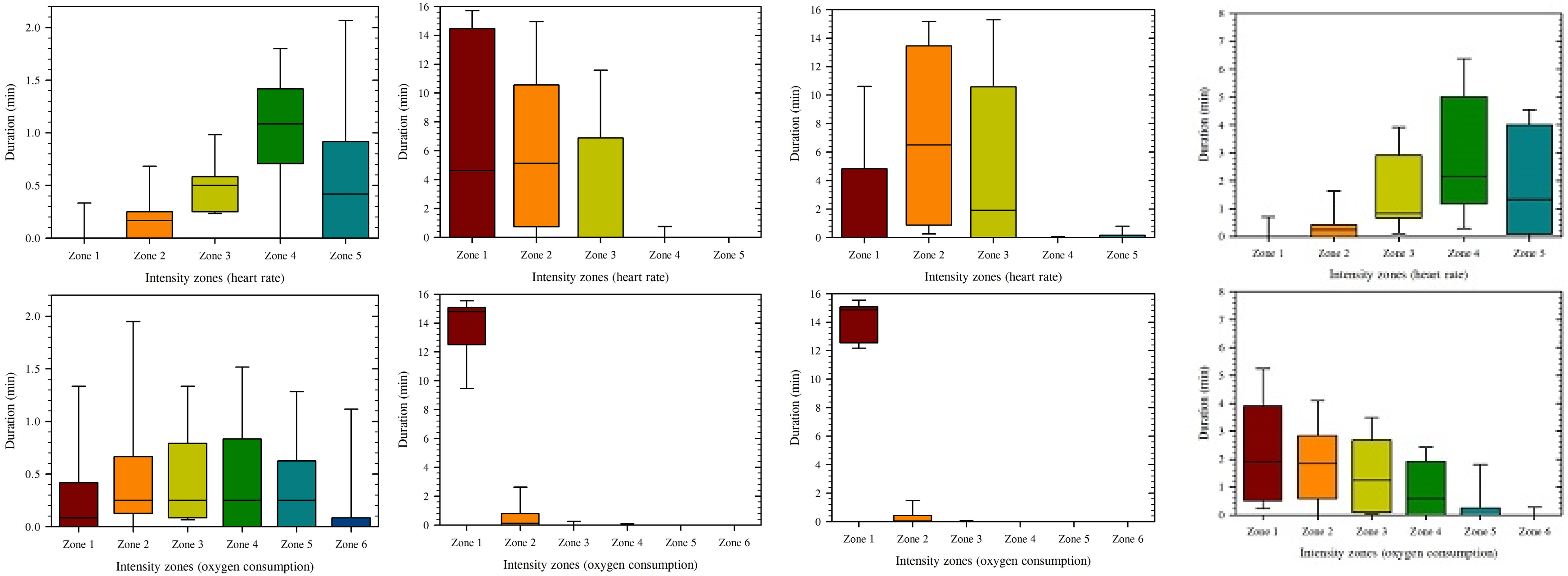

Figure 3.17: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (from left to right): the stair-climb simulation dragging a charge 38-mm hose (leading firefighter), prolonged use of 38-mm hose, prolonged use of 70-mm hose, 10.5-m ladder simulation. Zone thresholds were set at 25%, 50%, 75%, 90% and >90% of the heart rate reserve, and at increments of 0.5 $L.min^{-1}$ over the absolute oxygen consumption range 1.0-3.0 $L.min^{-1}$. The lower border of each box shows the 25th percentile, the line within the box is the median and the upper border is the 75th percentile. The error bars above and below each box define the 95th and the 5th percentiles.

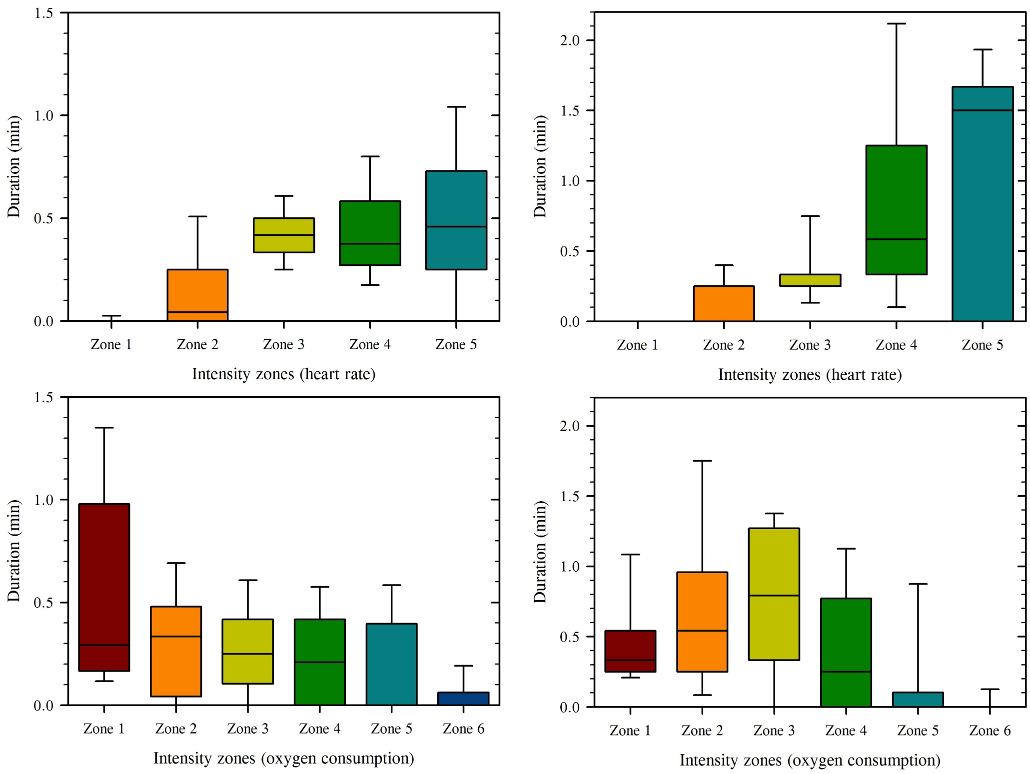

Figure 3.18: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain during the ventilation fan carry simulation (up stairs; left) and the sledge axe task (right). Zone thresholds were set at 25%, 50%, 75%, 90% and >90% of the heart rate reserve, and at increments of 0.5 $L.min^{-1}$ over the absolute oxygen consumption range 1.0-3.0 $L.min^{-1}$. The lower border of each box shows the 25th percentile, the line within the box is the median and the upper border is the 75th percentile. The error bars above and below each box define the 95th and the 5th percentiles.

rate and absolute oxygen consumption (Figure 3.16). Given the high materials handling component of this task (dragging charged 38-mm hose) it could therefore be described as a muscular strength and endurance task. However, it was also associated with cardiovascular endurance due the cardiovascular strain illustrated in the heart rate and absolute oxygen consumption intensity zones. The load present (106.57 kg firefighter) in the rescue task indicates a muscular strength and endurance task. Figure 3.16 provides complementary data for heart rate and absolute oxygen consumption, and there is a progressive increase in strain. Compared to previous simulations, the data for heart rate were shifted rightward indicating a more stressful activity. While the strain was still comparatively high, this trend was less evident within the absolute oxygen consumption data.

The distribution of strain across intensity zones for heart rate and oxygen consumption will assist in determining fitness classification in the overall task assessment. For instance, the stair climb (Figure 3.17) with fully charged 38-mm hose showed cardiovascular strain was predominantly located within zones three, four and five whilst metabolic strain was more evenly distributed. Thus, this task would seem to rely more heavily upon muscular endurance and strength than upon cardiovascular endurance.

3.3.2.5 Observational summary of all task simulations

This analysis involved an overall evaluation of each fire-fighting simulation, with the aim being to identify the fitness classifications essential to each occupational task. These fitness classifications were also derived from an analysis of the task duration, heart rate and oxygen cost. Movement patterns were also analysed including muscle actions. These observations are summarised in Tables 3.24 to 3.39.

The durations of these simulations ranged from 1.14 min to 52.33 min. Eight of these simulations were less than 5 min, three simulations were 5-15 min long, whilst five tasks lasted 15 min or longer. These occupational tasks are valid representations of the most physically demanding duties performed by contemporary firefighters (Phase One of this research; Chapter Two). 50% of these tasks relied on physiological attributes other than whole-body endurance (cardiorespiratory) fitness. A further 30% were dependent upon

Table 3.24: Overall occupational task assessment: hazmat incident simulation.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 40-50%
Secondary fitness classification (%)	Cardiovascular endurance: 25-35%
Tertiary fitness classification (%)	Muscular endurance: 15-25%
Primary movement action	Lift, then extended one-hand, team carry
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Lift and place (upper and lower body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Upper body
Major muscle groups involved	*Shoulder flexors*: eccentric and isometric actions *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Unilateral
Individual or team	Team
Load	Various: 8.45-52.25 kg
Approximate position of load and percentage of task time in that position	80% ground to waist (0-100 cm) 20% above shoulder (150+ cm)
Average task duration (min)	15.24 (range: 12.75-21.00)
Cardiovascular impulse (beats)	2037.41
Cardiovascular load (arbitrary units)	25.68
Ratings of perceived exertion (scale 6-20)	12.3 (range: 7-16)

Table 3.25: Overall occupational task assessment: motor-vehicle rescue simulation.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 50-60%
Secondary fitness classification (%)	Strength: 20-30%
Tertiary fitness classification (%)	Power: 10-20%
Primary movement action	Prolonged hold in different positions (level ground)
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Twist and turn (torso)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Upper torso
Major muscle groups involved	*Shoulder flexors, extensors and abductors:* concentric, eccentric and isometric actions *Elbow flexors*: concentric and isometric actions *Hip flexors and extensors:* isometric actions *Knee Extensors*: isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of movement symmetry	Bilateral
Individual or team	Individual, with team assistance if required
Load	Spreaders: 19.5 kg Shears: 13 kg Crowbar: 5.8 kg
Approximate position of load and percentage of task time in that position	60% waist to chest (100-150 cm) 25% above shoulder (150+ cm) 15% ground (0-80 cm)
Average task duration (min)	14.37 (range: 5.67-22.50)
Cardiovascular impulse (beats)	1830.59
Cardiovascular load (arbitrary units)	23.39
Ratings of perceived exertion (scale 6-20)	10.7 (range: 7-14)

Table 3.26: Overall occupational task assessment: rolling out 70-mm hose.

Attribute	Evaluation
Primary fitness classification (%)	Power: 60-70%
Secondary fitness classification (%)	Strength: 30-40%
Tertiary fitness classification (%)	- - -
Primary movement action	Squat with underarm throw, followed by walk and carry
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Throw (upper body)
Primary postural classification	Upright
Minor postural classification	---
Dominant body region	Upper body
Major muscle groups involved	*Shoulder flexors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions
Dominant mode of carriage	Unilateral
Individual or team	Individual
Load	16.6 kg of rolled 70-mm hose 5 kg 70-mm wide breach
Approximate position of load and percentage of task time in that position	60% waist (80-100 cm) 30% ground (0-80 cm) 10% chest (100-150 cm)
Average task duration (min)	1.68 (range: 1.25-2.42)
Cardiovascular impulse (beats)	241.62
Cardiovascular load (arbitrary units)	2.66
Ratings of perceived exertion	11.6 (range: 9-15)

Table 3.27: Overall occupational task assessment: coupling hoses.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 100%
Secondary fitness classification (%)	- - -
Tertiary fitness classification (%)	- - -
Primary movement action	One- or two-handed grip, hold and rotate in squatting or kneeling position, followed by a short walk
Primary movement classification	- - -
Minor movement classification	- - -
Primary postural classification	Kneel and crouch
Minor postural classification	Upright
Dominant body region	Hands
Major muscle groups involved	*Wrist supinators:* concentric and isometric actions *Wrist extensors:* isometric action *Elbow flexors*: isometric action
Dominant mode of carriage	- - -
Individual or team	Individual
Load	Resistive force provided by the couplings: not quantified
Approximate position of load and percentage of task time in that position	100% ground (0-80 cm)
Average task duration (min)	1.14 min (range: 0.75-1.83)
Cardiovascular impulse (beats)	153.93
Cardiovascular load (arbitrary units)	1.70
Ratings of perceived exertion	9.6 (range: 6-14)

Table 3.28: Overall occupational task assessment: locating and connecting a fire hydrant.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 40-50%
Secondary fitness classification (%)	Muscular endurance: 35-45%
Tertiary fitness classification (%)	Cardiovascular endurance: 10-20%
Primary movement action	Static carry with loads in both hands while walking on level ground
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Lift and place (upper body)
Primary postural classification	Upright
Minor postural classification	Kneel, squat, crouch
Dominant body region	Upper body
Major muscle groups involved	*Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Unilateral
Individual or team	Individual
Load	16.6 kg of rolled 70-mm hose Hydrant Standpipe: 8 kg Hydrant delivery elbow: 7.1 kg Hydrant bar: 1.8 kg
Approximate position of load and percentage of task time in that position	80% ground to waist (0-100 cm) 20% above shoulder (150+ cm)
Average task duration (min)	2.78 (range: 1.50-4.33)
Cardiovascular impulse (beats)	418.35
Cardiovascular load (arbitrary units)	4.62
Ratings of perceived exertion (scale: 6-20)	14.1 (range: 11-17)

Table 3.29: Overall occupational task assessment: dragging charged 70-mm hose.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 50-60%
Secondary fitness classification (%)	Strength: 30-40%
Tertiary fitness classification (%)	Power: 10-20%
Primary movement action	One-sided pull with uneven centre of gravity, then with intermittent periods of walking
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Push, pull, drag (upper and lower body)
Primary postural classification	Upright
Minor postural classification	- - -
Dominant body region	Upper body
Major muscle groups involved	*Shoulder flexors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions [all actions are predominately isometric]
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	70-mm hose: ~115 kg, 7-8 kg off the ground
Approximate position of load and percentage of task time in that position	100% waist to shoulder (100-150 cm)
Average task duration (min)	7.09 (range: 7.08-7.17)
Cardiovascular impulse (beats)	961.53
Cardiovascular load (arbitrary units)	10.62
Ratings of perceived exertion (scale: 6-20)	10.5 (range: 6-13)

Table 3.30: Overall occupational task assessment: fire-attack simulation.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 30-40%
Secondary fitness classification (%)	Strength: 40-50%
Tertiary fitness classification (%)	Cardiovascular endurance: 20%
Primary movement action	Extended squat and crab-crawl, with one-sided pull and uneven centre of gravity
Primary movement classification	Push, pull, drag (whole body)
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Kneel, squat, crouch
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Shoulder flexors*: concentric and isometric actions *Elbow flexors*: isometric action *Knee flexors*: concentric action *Hip flexors*: concentric and isometric actions *Back extensors*: concentric and isometric actions *Trunk Stabilisers*: isometric actions
Dominant mode of carriage	Unilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	100% ground to waist (0-100 cm)
Average task duration (min)	4.16 (range: 3.42-5.25)
Cardiovascular impulse (beats)	593.89
Cardiovascular load (arbitrary units)	6.56
Ratings of perceived exertion (scale 6-20)	13.4 (range: 9-17)

Table 3.31: Overall occupational task assessment: firefighter rescue simulation (one person).

Attribute	Evaluation
Primary fitness classification (%)	Strength: 50-60%
Secondary fitness classification (%)	Power: 30-40%
Tertiary fitness classification (%)	Dynamic balance: 10-20%
Primary movement action	Isometric hold with backward walking on level ground
Primary movement classification	Push, pull, drag (lower body)
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Kneel, squat, crouch
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Elbow flexors*: isometric action *Knee flexors*: concentric action *Hip extensors*: concentric action *Back extensors*: isometric action *Trunk Stabilisers*: isometric action
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	Firefighter with full protective ensemble: 106.57 kg
Approximate position of load and percentage of task time in that position	80% ground to waist (0-100 cm) 20% waist to chest (100-150 cm)
Average task duration (min)	3.84 (range: 2.92-5.17)
Cardiovascular impulse (beats)	617.46
Cardiovascular load (arbitrary units)	6.82
Ratings of perceived exertion (scale 6-20)	17.0 (range: 13-19)

Table 3.32: Overall occupational task assessment: bushfire (hose-drag) simulation.

Attribute	Evaluation
Primary fitness classification (%)	Cardiovascular endurance: 50-60%
Secondary fitness classification (%)	Strength and power: 20-30%
Tertiary fitness classification (%)	Muscular endurance: 10-20%
Primary movement action	One-sided pull on uneven and hilly terrain
Primary movement classification	Push, pull, drag (lower body)
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Shoulder extensors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	60% waist (80-100 cm) 20% ground (0-80 cm) 20% waist to shoulder (100-150 cm)
Average task duration (min)	52.33
Cardiovascular impulse (beats)	7461.9
Cardiovascular load (arbitrary units)	82.18
Ratings of perceived exertion (scale 6-20)	12.8 (level ground) 13.8 (hilly)

Table 3.33: Overall task assessment: stair climb with charged 38-mm hose: lead position.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 40-50%
Secondary fitness classification (%)	Power: 25-35%
Tertiary fitness classification (%)	Strength endurance: 15-35%
Primary movement action	Stair climb with one-sided pull, and uneven centre of gravity
Primary movement classification	Push, pull, drag (lower body)
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Shoulder flexors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	50% chest to shoulder (100-150 cm) 25% waist (80-100 cm) 25% ground (0-80 cm)
Average task duration (min)	2.46 (range: 1:00-4.33)
Cardiovascular impulse (beats)	383.46
Cardiovascular load (arbitrary units)	4.83
Ratings of perceived exertion (range: 6-20)	15.2 (range: 13-18)

Table 3.34: Overall task assessment: stair climb with charged 38-mm hose: support.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 40-50%
Secondary fitness classification (%)	Power: 25-35%
Tertiary fitness classification (%)	Strength endurance: 15-35%
Primary movement action	Stair climb with one sided pull, and uneven centre of gravity
Primary movement classification	Push, pull, drag (lower body)
Minor movement classification	Carry and hold (upper body)
Primary postural classification	Stoop and forward bend
Minor postural classification	Upright
Dominant body region	Lower body
Major muscle groups involved	*Shoulder flexors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	40% waist (80-100 cm) 35% ground (0-80 cm) 25% chest to shoulder (100-150 cm)
Average task duration (min)	3.50 (range: 2.58-6.08)
Cardiovascular impulse (beats)	552.36
Cardiovascular load (arbitrary units)	7.04
Ratings of perceived exertion (range: 6-20)	15.6 (range:12-19)

Table 3.35: Overall task assessment: prolonged hose-use simulation: 38-mm hose.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 70-80%: minimal strain
Secondary fitness classification (%)	Strength: 20-30%: minimal strain
Tertiary fitness classification (%)	- - -
Primary movement action	Static, two-handed hold in upright position
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Push, pull, drag (upper body)
Primary postural classification	Upright
Minor postural classification	- - -
Dominant body region	Upper body
Major muscle groups involved	*Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action *[minimal muscular work in this task]*
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	38-mm hose: ~35 kg
Approximate position of load and percentage of task time in that position	100% waist to chest (100-150 cm)
Average task duration (min)	15.36 (range: 15.08-16.00)
Cardiovascular impulse (beats)	1733.40
Cardiovascular load (arbitrary units)	21.61
Ratings of perceived exertion (range: 6-20)	10.3 (range: 7-15)

Table 3.36: Overall task assessment: prolonged hose-use simulation: 70-mm hose.

Attribute	Evaluation
Primary fitness classification (%)	Muscular endurance: 70-80%
Secondary fitness classification (%)	Strength: 20-30%
Tertiary fitness classification (%)	- - -
Primary movement action	Static, two-handed hold in upright position
Primary movement classification	Carry and hold (upper body)
Minor movement classification	- - -
Primary postural classification	Upright
Minor postural classification	- - -
Dominant body region	Upper body (shoulders)
Major muscle groups involved	*Shoulder flexors and abductors:* concentric and isometric actions *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action [all muscles predominately isometric]
Dominant mode of carriage	Bilateral
Individual or team	Team
Load	70-mm hose: ~115 kg
Approximate position of load and percentage of task time in that position	70% waist to chest (100-150 cm) 30% at shoulder level (~150 cm)
Average task duration (min)	15.40 (range: 15.08-15.67)
Cardiovascular impulse (beats)	1892.46
Cardiovascular load (arbitrary units)	23.68
Ratings of perceived exertion (range: 6-20)	10.7 (range: 7-15)

Table 3.37: Overall occupational task assessment: 10.5-m ladder use simulation.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 30-40%
Secondary fitness classification (%)	Muscular endurance: 30-40%
Tertiary fitness classification (%)	Agility and balance: 20-30%
Primary movement action	One-handed carry on level ground, and two-handed actions during raise and lower, and whilst climbing the ladder
Primary movement classification	Carry and hold (upper body)
Minor movement classification	Lift and place (upper body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Upper body
Major muscle groups involved	*Shoulder flexors:* concentric, eccentric and isometric actions *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Both unilateral and bilateral
Individual or team	Team
Load	Ladder (extension): 49.6 kg
Approximate position of load and percentage of task time in that position	40% waist (80-100 cm) 30% above shoulder (150+ cm) 20% chest (100-150 cm) 10% ground (0-80 cm)
Average task duration (min)	7.28 (range: 5.50-10.25)
Cardiovascular impulse (beats)	1157.52
Cardiovascular load (arbitrary units)	14.47
Ratings of perceived exertion (range: 6-20)	13.2 (range: 7-17)

Table 3.38: Overall occupational task assessment: ventilation fan carry simulation.

Attribute	Evaluation
Primary fitness classification (%)	Strength: 50-60%
Secondary fitness classification (%)	Cardiovascular endurance: 20-30%
Tertiary fitness classification (%)	Dynamic balance: 10-20%
Primary movement action	Stair climb with one-, and possibly two-handed carry
Primary movement classification	Carry and hold (whole body)
Minor movement classification	Lift and place (upper body)
Primary postural classification	Upright
Minor postural classification	Stoop and forward bend
Dominant body region	Lower body
Major muscle groups involved	*Elbow flexors*: concentric and isometric actions *Hip extensors*: concentric and isometric actions *Knee Extensors*: concentric and isometric actions *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Unilateral
Individual or team	Team
Load	Ventilation fan: 35 kg
Approximate position of load and percentage of task time in that position	80% ground to waist (0-100 cm) 20% above shoulder (150+ cm)
Average task duration (min)	1.51 (range: 1.08-2.33)
Cardiovascular impulse (beats)	237.32
Cardiovascular load (arbitrary units)	2.97
Ratings of perceived exertion (range: 6-20)	15.3 (range: 11-17)

Table 3.39: Overall occupational task assessment: sledge axe entry simulation.

Attribute	Evaluation
Primary fitness classification (%)	Power: 35-45%
Secondary fitness classification (%)	Cardiovascular endurance: 35-45%
Tertiary fitness classification (%)	Muscular endurance: 15-25%
Primary movement action	Two-handed rotation (swing)
Primary movement classification	Upper-body rotation (swing)
Minor movement classification	Twist and turn (upper body)
Primary postural classification	Upright
Minor postural classification	---
Dominant body region	Upper body
Major muscle groups involved	*Shoulder flexors, abductors and rotators:* concentric and eccentric actions *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee extensors*: concentric and isometric actions *Back extensors*: concentric, eccentric and isometric actions *Trunk stabilisers*: concentric, eccentric and isometric actions
Dominant mode of carriage	Bilateral
Individual or team	Individual
Load	Sledge axe: 4.7 kg
Approximate position of load and percentage of task time in that position	100% waist to above shoulder (80+ cm)
Average task duration (min)	2.50 (range: 2.33-2.83)
Cardiovascular impulse (beats)	412.61
Cardiovascular load (arbitrary units)	5.26
Ratings of perceived exertion (range: 6-20)	15.4 (range: 10-19)

whole-body fitness, either in the form of cardiorespiratory or muscular endurance. All tasks involved some form of manual handling or load carriage.

The dominant form of load carriage was performed with a hold and carry action and loads utilised in these simulation ranged from 4.7 (sledge axe) to 49.5 kg (ladder; though this was a two person lift; Appendix Three). Three occupational tasks involved movement patterns dominated by the pushing, pulling or dragging of objects greater than 20 kg in mass. Ratings of perceive exertion ranged from 9.6 to 17.0 (scale 6-20; Table 3.40), with the most difficult perceived task being the firefighter rescue. This is a predictable outcome given the psychological stress associated with the critical, lifesaving nature of this task.

3.3.3 Simulation sixteen: Structural search and rescue (hot-fire cell: in pairs)

3.3.3.1 Example experimental data

Hot conditions (simulation one)

These simulations averaged 25.64 min, yet every fire-fighter terminated the activity with a deep-body temperature greater than 39°C. Body core temperature data for all eight firefighters who participated within both stages of this fire-fighting stimulation are presented in Figure 3.19 and heart rate is presented in Figure 3.20. This was measured using a gastrointestinal pill. The data indicates that each firefighter was warm prior to exposure. This was predominately due to the wearing of the personal protective clothing. The rise in core temperature of each firefighter was linear. The mean rate of rise was 0.08°C.min^{-1} (SD 0.02). This linear response (derived from regression analyses) permitted an extrapolation of these data to predict the time taken to reach a core temperature of 40°C. This figure could be viewed as a temperature beyond which firefighters may become seriously impaired, incapacitated or even suffer from heat illness. When the time taken to reach this temperature was predicted for each firefighter (in addition to each simulation's duration), it was found to average just a further 10.6 min (SD 4.9; range: 4.0-15.0 min).

Temperate conditions (simulation two)

As noted earlier, the structural search and rescue was comprised of several tasks that had already been evaluated within this series of simulations. However, the simulation was

Table 3.40: Rating of perceived exertion (Borg, 1962a) for all fire-fighting simulations. Data are presented as means. Scale progresses from 6 (minimal work) to 20 (maximal effort).

Trade-task simulation	Rating of perceived exertion (scale 6-20)
Firefighter rescue	17.0
Sledge axe entry	15.4
Stair climb with charged hose	15.4
Ventilation fan carry up stairs	15.3
Locating and connecting a fire hydrant	14.1
10.5 m ladder use	13.7
Fire-attack	13.4
Bushfire (hose-drag)	13.2
Hazmat	12.3
38-mm hose roll out	11.6
Motor vehicle rescue	10.7
Prolonged use of 70-mm hose	10.7
Dragging charged 70-mm hose	10.5
Prolonged use of 38-mm hose	10.3
Hose coupling	9.6

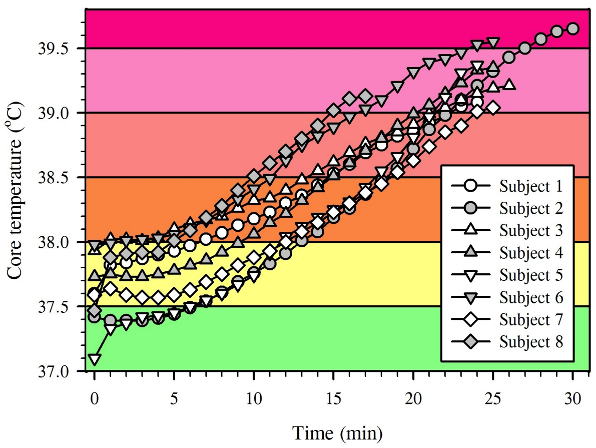

Figure 3.19: Core temperature response of all eight firefighters during the first (heated) structural search and rescue simulation.

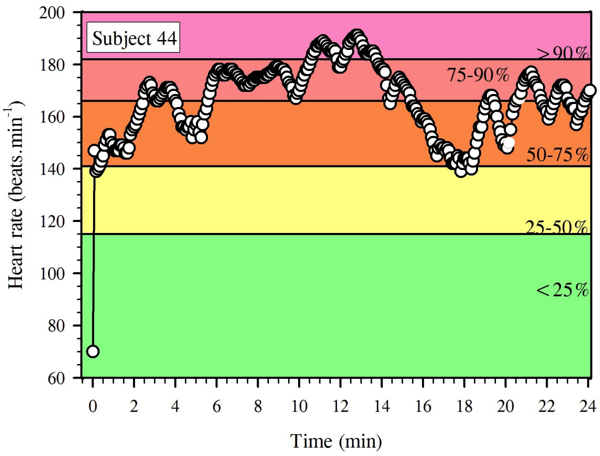

Figure 3.20: Heart rate response of one firefighter during the first (heated) structural search and rescue simulation.

added at the request of the Research Team, since it provided an opportunity to join several tasks into a single simulation with high ecological validity. Thus, this simulation provided another setting in which to approximate a real-life fire-fighting situation. In addition, it would provide a cross-validation of the fire-attack simulation, *albeit* using data collected from another pool of firefighters. Time-series data is provided for one firefighter for heart rate (Figure 3.21), absolute oxygen consumption (Figure 3.22) and ventilation (Figure 3.23).

Physiological and psychophysical strain

Table 3.41 summarises physiological strain observed during this simulation. Average data are presented for the resting and simulation states. Minimal and maximal range parameters define the lower and upper boundaries of physiological strain observed during the simulation. Oxygen consumption data are presented in absolute and relative terms. Across all firefighters, the mean heart rate had a 95% probability of falling between 135-163 beats.min^{-1}. Similarly, the mean absolute oxygen consumption would lie within the zone from 1.41 to 1.81 L.min^{-1}. In comparison with the fire-attack simulation (Table 3.10), these range data displayed considerable overlap, with the mean heart rate falling within the range from 135 to 151 beats.min^{-1}, whilst the mean absolute oxygen consumption fell between 1.34-1.72 L.min^{-1}. Moreover, the averages derived for specific oxygen consumption, minute ventilation, tidal volume and breathing frequency were quite comparable across the two simulations. This provides the author with confidence of a valid characterisation of this occupational activity (between simulations seven (fire attack) and sixteen (hot cell task).

In Figure 3.24, observations for heart rate and absolute oxygen consumption are summarised. Graphs display work rate intensities, showing times spent (ordinate) within zones of different physiological strain (abscissa) during the simulation, which lasted 19.57 min. The medians[4] within each box (horizontal lines) show the times spent within each strain zone.

[4] This time is closest to the middle of the range of times observed across all firefighters during the simulation.

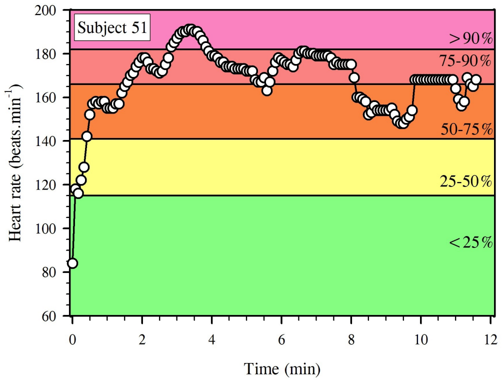

Figure 3.21: Heart rate response of one firefighter during the second (temperate) structural search and rescue simulation.

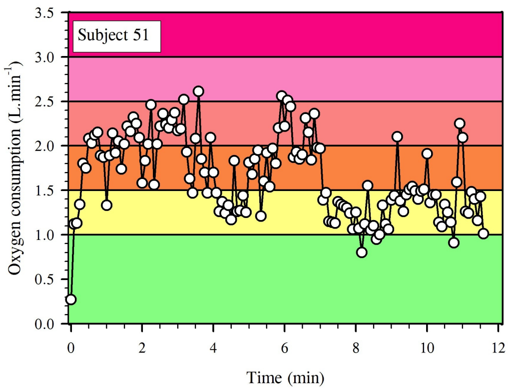

Figure 3.22: Oxygen consumption response of one firefighter during the second (temperate) structural search and rescue simulation.

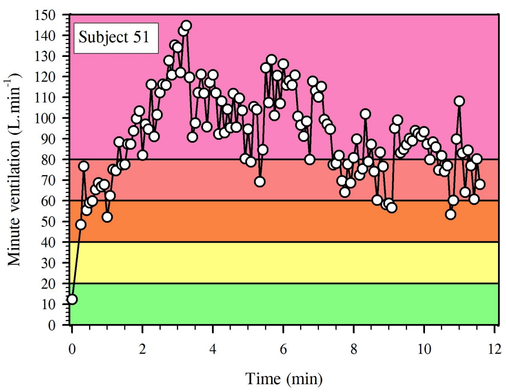

Figure 3.23: The ventilatory response of one firefighter during the second (temperate) structural search and rescue simulation.

Table 3.41: Summary parameters for physiological strain in firefighters ($N=8$) performing the second (temperate) structural search and rescue simulation. Data are means with standard deviations in parenthesis for the resting and simulation conditions. Minimal, maximal and confidence interval data relate only to the simulation.

Variable	Rest	Mean	Minimal	Maximal	95% confidence interval
Heart rate (beats.min^{-1})	79 (15)	149 (20)	91	194	14
Absolute oxygen consumption (L.min^{-1})	0.32 (0.09)	1.61 (0.29)	0.38	3.37	0.20
Specific oxygen consumption (mL.kg^{-1}.min^{-1})	3.83 (0.79)	15.09 (2.17)	4.05	30.39	1.51
Specific oxygen consumption (mL.kg$^{-0.67}$.min^{-1})	16.41 (3.63)	70.52 (10.61)	18.11	143.73	7.35
Minute ventilation (L.min^{-1})	13.98 (2.43)	67.71 (14.49)	20.85	144.65	10.04
Tidal volume (L)	0.74 (0.08)	1.79 (0.25)	0.52	3.55	0.17
Breathing frequency (breaths.min^{-1})	19 (3)	37 (7)	14	66	5

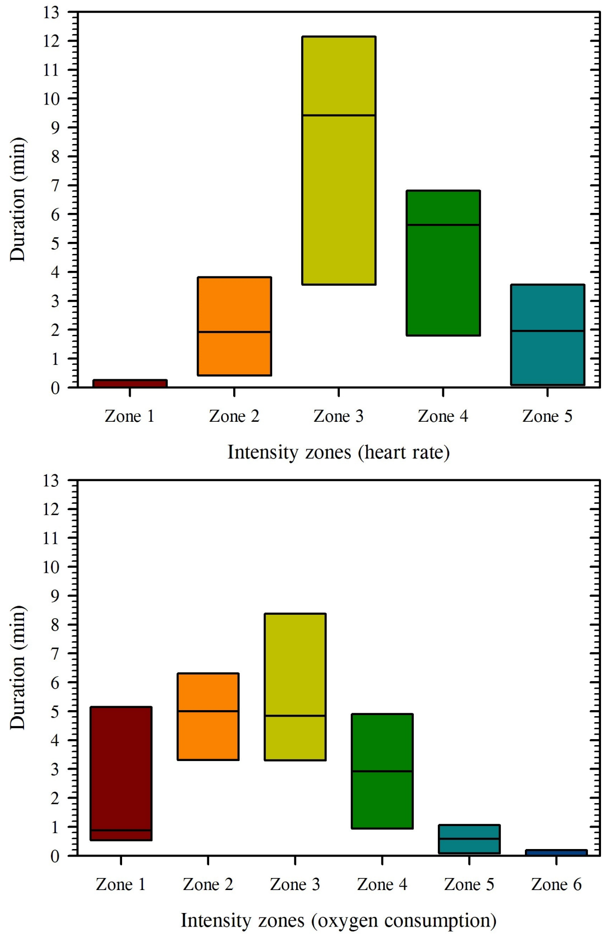

Figure 3.24: Box plots for heart rate and oxygen consumption showing times spent within zones of progressively increasing physiological strain (moving rightwards) during the second (temperate) structural search and rescue simulation (whiskers were not calculated due to the smaller sample size).

Observational summary

The final analysis involved an overall evaluation of the two primary parts of this simulation: the hose-drag and dummy-drag activities. The aim of these analyses was to identify the critical fitness classifications for each task. The method used to derive these fitness classifications was the same as previously discussed (3.3.2.5), with an aim to summarise the main cardiovascular, metabolic and muscular strain indices of each occupational task. The results of this analysis for the hose-drag and dummy-drag activities are illustrated in Table 3.42.

3.3.4 The distillation and filtration of fire-fighting tasks - Final criterion list

The results of the filtration process (Figure 3.10) are presented in Table 3.43.
On the basis of the these analytical processes, the following criterion fire-fighting tasks were grouped into four activity classes. Activities within each class possess similar physical and physiological attributes. These may be used to develop screening tests that could be used to identify capable and robust potential fire-fighting recruits.

- Class one: tasks one (hazmat), three (rolling out 70-mm hose), five (hydrant location and connection), thirteen (10.5-m ladder use) and fourteen (ventilation fan carry)
- Class two: task fifteen (using a sledge axe to gain entry), two (motor-vehicle rescue).
- Class three: tasks seven (fire attack), task nine (dragging charged 38-mm hose [uneven terrain])
- Class four: eight (firefighter rescue) and ten (stair climb dragging a charged 38-mm hose).

It is recommended these activity classes be distilled further and task constraints analysed. Thus, further investigation and breakdown of the critical elements of these trade tasks can be conducted and this is the aim of Chapter Four, the final study of this dissertation.

The rationale for analytical task assessments within this filtration mechanism have been discussed previously (Section 3.2.7). This distillation/filtration approach specifically

Table 3.42: Overall occupational task assessment: second (temperate) structural search and rescue simulation.

Attribute	Evaluation
Primary fitness classification (%)	Hose-drag tasks: Muscular endurance 50% Dummy-drag tasks: Strength 30-40%
Secondary fitness classification (%)	Hose-drag tasks: Cardiovascular endurance 30-40% Dummy-drag tasks: Muscular endurance 30-40%
Tertiary fitness classification (%)	Hose-drag tasks: Power 10-20% Dummy-drag tasks: Cardiovascular endurance 20-30%
Primary movement action	Hose-drag tasks: Stair climb with one-sided pull, and uneven centre of gravity Dummy-drag tasks: Isometric hold with backwards walking down stairs
Primary movement classification	Both tasks: Push, pull, drag (whole body)
Minor movement classification	Both tasks: Carry and hold (upper body)
Primary postural classification	Hose-drag tasks: Upright Dummy-drag tasks: Kneel, squat, crouch
Minor postural classification	Hose-drag tasks: Stoop and forward bend Dummy-drag tasks: Upright
Dominant body region	Lower body
Major muscle groups involved	**Hose-drag tasks:** *Shoulder extensors*: concentric action *Elbow flexors*: concentric and isometric actions *Hip flexors*: concentric and isometric actions *Knee extensors:* concentric and isometric actions *Trunk stabilisers*: concentric and isometric actions **Dummy-drag tasks:** *Elbow flexors*: isometric action *Knee flexors*: eccentric action *Hip extensors*: eccentric action *Back extensors*: isometric action *Trunk stabilisers*: isometric action
Dominant mode of carriage	Both bilateral

Attribute	Evaluation
Individual or team	Individual
Load	Hose-drag tasks: 38 mm hose: ~ 35 kg Dummy-drag tasks: 50 kg and 70 kg dummies
Approximate position of load and percentage of task time in that position	**Hose-drag tasks:** 50% upper torso (100-150 cm) 25% waist (80-100 cm) 25% ground (0-80 cm) **Dummy-drag tasks:** 60% waist (80-100 cm) 20% upper torso (100-150 cm) 20% ground (0-80 cm)
Average task duration (min)	19.57 (range: 11.58-23.42)
Cardiovascular impulse (beats)	2913.90
Cardiovascular load (arbitrary units)	37.11
Ratings of perceived exertion (scale: 6-20)	13.1 (range: 8-17)

Table 3.43: Simulation (1-15; Table 3.2) classifications based upon the results of the filtration process illustrated in Figure 3.10. Whole-tasks may appear in more than one cell (*i.e.* tasks 8, 10 and 14).

Strength and muscular-endurance activities						Cardiorespiratory-endurance activities		
Upper-body activities			Lower-body activities			Loaded		Unloaded
Push, pull, drag	< 20 kg		Push, pull, drag	< 20 kg		< 20 kg	15	
	20-30 kg			20-30 kg	7			
	> 30 kg	8, 10		> 30 kg	8, 10			
Hold and carry	< 20 kg	2, 3, 5, 11	Hold and carry	< 20 kg				
	20-30 kg	1, 6, 12, 13, 14		20-30 kg	14	20-30 kg		
	> 30 kg			> 30 kg				
Lift and place	< 20 kg		Lift and place	< 20 kg				
	20-30 kg			20-30 kg				
	> 30 kg			> 30 kg		> 30 kg	9	
Twist, turn	< 20 kg		Twist, turn	< 20 kg				
	20-30 kg			20-30 kg				
	> 30 kg			> 30 kg				

focussed on benefiting the next study of this project, which centres upon the development of physiological screening tests for potential recruits. Thus, to improve test efficiency, activities were culled to minimise the duplication of movement patterns and loads. This was seen as an appropriate and necessary measure, and this was confirmed by Fire & Rescue NSW. To the author's knowledge, there is little previous literature to provide an evidence based rationale for this specific approach. However, given the extensive nature of the tasks within physically demanding occupations, it becomes necessary to cull tasks to comply with the requirements for screening test administration (personal communication, Fire & Rescue NSW; Jamnik *et al.*, 2010b). Whilst it is critical to aim for physiological employment standards to encompass a broad range of physically demanding tasks, it is of similar importance to minimise redundancy and duplication in the chosen set of tasks for screening tests (Payne and Harvey, 2010). Thus, some degree of filtration is necessary. It should also be noted that this was not the sole criterion for the final trade-task list. If tasks were deemed critical by subject matter experts (Management Team), they were retained for the final trade-task list. This verification process is common when constructing screening test items through subjective task inclusion/exclusion criteria (Rayson, 2004; Jamnik *et al.*, 2010b). This collaboration is crucial, especially given the lack of distinct job task analysis guidelines in the present literature (Larsen and Aisbett, 2012). Finally, it is vital the validity and reliability of these task inclusion/exclusion procedures are tested, however this is beyond the realms of this dissertation. These processes could potentially include the application of principal component analyses to confirm similar results between tasks, or component rotation techniques to reduce the overlap of task components (Hair *et al.,* 1998).

3.4 DISCUSSION

The evaluation and quantification of the fifteen essential, physically demanding trade tasks in our investigation includes the transportation of hoses, heavy manual handling, ladder use, stair climbing, and rescue, hazmat and bush related activities (Table 3.23). These analyses lead to the development of a final list of eleven criterion trade tasks (Section 3.3.4) by sub-dividing tasks into strength, muscular-endurance and cardiorespiratory-endurance activities (Figure 3.10; Table 3.43). The quantification of the essential, physically demanding tasks of fire fighting as performed within New South Wales, at least to the author's knowledge, have not been conducted previously. Thus, an evaluation of these analyses was the logic behind this investigation. This process aimed to determine the physical and physiological attributes necessary to perform the most essential, physically demanding and critical fire-fighting duties in an optimal and safe manner. These findings provide adequate progression to the next phase of research (Chapter Four), which centres upon the development of legally defensible physiological screening tests for possible use within Fire & Rescue NSW recruiting. Indeed, this was the overall purpose of this dissertation.

3.4.1 The quantification and evaluation of essential, physically demanding trade tasks

Many authors have reported physiological measures as a means to quantify and evaluate the minimal human expenditure required to perform simulated physically demanding tasks (Lemon and Hermiston, 1977b; Davis *et al.*, 1982; Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001a and b; Taylor *et al.*, 2003; Rayson *et al.*, 2004). For instance, previous investigators have reported oxygen uptake measures as a means to quantify the minimal human expenditure required to perform simulated fire-fighting tasks (Lemon and Hermiston, 1977b; Davis *et al.*, 1982; Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001a), with relative values ranging from 33.5 $mL.kg^{-1}.min^{-1}$ (Lemon and Hermiston, 1977b) to 45 $mL.kg^{-1}.min^{-1}$ (Gledhill and Jamnik, 1992a). Furthermore, the cardiac strain experienced during the performance of fire-fighting drills and simulations, and its approach to near maximal levels, are well established (Manning and Griggs, 1983; Smolander *et al.*, 1985; Sothmann *et al.*, 1991, Lusa *et al.*, 1993; Williford *et al.*, 1999; Smith *et al.*, 2001; Willliams-Bell *et al.*, 2009), with mean heart rates ranging from 157 $beats.min^{-1}$ (Smolander *et al.*, 1985) to 189 $beats.min^{-1}$ (Smith *et al.*, 2001).

Given the high metabolic demands of fire fighting (Table 3.23; Lemon and Hermiston, 1977b; Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001a), these increases in physiological strain (Appendix Four) are predictable outcomes, as cardiorespiratory variables have long been known to increase in proportion to increments in metabolic demand (Åstrand and Ryhming, 1954). The following text will provide evidence based upon the results of our evaluations, and the quantification and filtration processes, to support the final list of eleven criterion trade tasks (Section 3.3.4) representing a valid sub-set of tasks. This process also aimed to minimise the duplication of muscular movements between criterion tasks. It is proposed that this sub-set of tasks could be employed as part of a potential physiological screening test, to ensure the firefighter would possess the minimal physical and physiological attributes to perform fire-fighting duties in a safe and efficient manner.

3.4.1.1 Strength and muscular-endurance activities

85% of tasks investigated in our study comprised primarily either muscular strength and muscular endurance (Table 3.43). These data are consistent with results of previous authors, who have shown fire-fighting simulations entail muscular strength (Gledhill and Jamnik, 1992a; Lusa *et al.*, 1994; Henderson *et al.*, 2007) and strength (muscular) endurance (Lusa *et al.*, 1994; Taylor *et al.*, 2010b). The principal action identified in nine of the essential physically demanding tasks was the hold/carry (Table 3.43). These results are consistent with previous findings involving Australian rural (Phillips, *et al.*, 2012) and metropolitan firefighters (Taylor *et al*,. 2010b). Phillips and colleagues (2012) identified and characterised seven physically demanding tasks performed by these firefighters. All seven tasks comprised carry actions, four comprised dragging and three consisted of dig/rake actions. The preponderance of the carry action in our results reflects the prevalence of external loads involved in fire-fighting tasks as performed within NSW (Appendix Three). Indeed, no unloaded activities exist among the fifteen essential, physically demanding tasks (Table 3.43).

All nine tasks identified as hold and carry tasks in our investigation involved the upper body (Table 3.43). One such task was the use of the 10.5-m ladder. Previous investigators have reported ladder use to induce significant physiological strain, especially in subjects performing an aerial climb with mean heart rates of 166 beats.min^{-1} (SEM 1; Gledhill and Jamnik, 1992a). This was consistent with our results for the ladder climb (Table 3.19), with mean heart rate reaching 161 beats.min^{-1}. Furthermore, this task entails the greatest external load during unilateral carriage, along with the hazmat task (*e.g.* both tasks 25-26 kg; Appendix Three). Considerable cardiac strain was also apparent in the location and connection of a hydrant (150 beats.min^{-1}), entire ladder simulation (159 beats.min^{-1}) and stair climb with a ventilation fan (157 beats.min^{-1}) tasks. This was also alike to the mean heart rates elicited in tasks of a similar nature studied in Gledhill and Jamnik (1992a), for instance the carriage of equipment up stairs (156 beats.min^{-1}; SEM 3). Collectively, six of the seven takes in this investigation involving load carriage of 15 kg or greater were hold and carry tasks (Appendix Three). Thus, it is apparent hold and carriage tasks entail a high level of physiological and muscular strain, justifying the filtration processes utilised within our investigation, and lending support to the inclusion of these tasks in the final criterion trade-task list (Section 3.3.4). This is important, as potential fitness tests for fire-fighting applicants should reflect the most demanding trade tasks of the occupation (Gledhill and Jamnik, 1992a; Constable and Palmer, 2000; Jamnik *et al.*, 2010a).

Four tasks were identified as push, pull, drag tasks in our investigation, two of which involved the upper and lower body (Table 3.43). The stair climb with fully charged 38-mm hose and halligan tool was one task identified which induced considerable physiological strain entailing these characteristics. Previous investigations have shown loaded stair climbing to elicit considerable physiological strain (Holmér and Gavhed, 2007; Taylor *et al.*, 2010b; Milligan *et al.*, 2010). Indeed, stair climbing tasks involving a high-rise pack and halligan tool (similar to the stair climb with fully charged 38-mm hose; Section Methods 3.2.4.10) were the most physically demanding of tasks for a study completed on Canadian firefighters (Gledhill and Jamnik, 1992a), evoking a mean oxygen uptake of 44.0 mL.kg^{-1}.min^{-1} (SEM 1.5) and mean heart rate of 163 beats.min^{-1} (SEM 2). In the present investigation, the stair climb with fully charged 38-mm hose and stair climb with ventilation fan tasks both exceeded mean heart rates of 155 beats.min^{-1} (Table 3.23) whilst mean oxygen uptake for the stair climb with fully charged 38-mm hose was the greatest for all tasks (1.97 L.min^{-1}; Table 3.23). These data are consistent with significant muscular and metabolic demands imposed by this task, even though its average duration was only 2.46 min. This task also induced considerable cardiovascular strain, predominantly illustrated within the three most stressful heart rate zones (Figure 3.17). However, variation across the literature does exist when comparing loaded stair climbing (Holmér and Gavhed, 2007; Table 3.23), and this is perhaps attributable to the different stepping (motion) patterns of subjects performing such activities (Shiomi, 1994). Nevertheless, it is clear loaded stair climbing is extremely physically demanding, justifying its place in the final criterion trade-task list (Section 3.3.4; Jamnik *et al,* 2010a).

The second task (of four) which involved muscular actions of push, pull, drag characteristics, and entailed both the upper and lower body, was the firefighter rescue (Table 3.43). Performing the rescue of a fellow firefighter was established as the most difficult and critical fire-fighting task in Chapter Two of this dissertation. Quantification of this task in the present investigation (Chapter Three) involved dragging a fully clothed and protected firefighter (106.57 kg) to safety in ambient conditions. Subjects performing this task reported a mean heart rate of 161 beats.min^{-1} (Table 3.23). This task also resulted in a mean oxygen cost of 1.68 L.min^{-1} and mean perceived rating of exertion of 17.0 (Table 3.40). The high physiological demand associated with rescuing individuals is well established (Lusa *et al.*, 1993; Bilzon *et al.*, 2001a; Taylor *et al.,* 2010b). Our data is consistent with these investigations, which show that metabolic demand increases under the influence of an external load (Cavagna *et al.*, 1963; Beekley *et al.*, 2007), causing increases in various cardiorespiratory variables, including heart rate (Queseda *et al.*, 2000; Beekley *et al.*, 2007). In this study, the metabolic cost of this task was likely attributable to the large external load placing an increasing strain on the activation of the working musculature (Soule *et al.*, 1969; Knapik *et al.*, 1996). Thus, it would seem that the primary effector of heart rate for the firefighter rescue was the product of the external loads.

Although the criticality of the firefighter rescue cannot be argued, justifying its place in the final criterion trade-task list (Section 3.3.4; Jamnik *et al.*, 2010a), the aerobic demand suggests this was not the most demanding task (stair climb with full charged 38-mm hose was the greatest for all tasks: 1.97 L.min^{-1}; Table 3.23). However, whilst the force, strength and power of this task were most likely elevated, they could not be quantified in this study due to time constraints. Despite the fact subjective analyses were conducted for this task (Table 3.31), further research is required to quantify these mechanical loads, in addition to physiological variables (such as heart rate and oxygen consumption), to give an accurate representation of such critical tasks.

Additionally, there were instances in our investigation where heart rate was a poor reflector of the physiological demand for the task. For instance, mean heart rate for dragging a charged 70-mm hose laterally demonstrated moderate cardiovascular strain, the performance of which subjects spent prolonged durations at 50% of their heart rate reserve (Figure 3.16). Moreover, mean oxygen consumption reflected a relatively low physiological strain 0.83 $L.min^{-1}$ for the task. Thus, it would seem heart rate was attributed to the load held (70-mm hose; of which 7-8 kg was held by the firefighter). However, given this load was fairly light and subjects rated it the third easiest task (mean perceived exertion 10.5 out of scale 6-20; Table 3.40), heart rate was most likely a function of extraneous factors. For example, the charged 70-mm hose drag was performed as the final activity as part of the simulations performed in series (Sections 3.2.4.3-3.2.4.6). As such, it is likely there was a cumulative heat effect (McLellan, 2008), which is known to drive heart rate upwards, and out of proportion to the increase in metabolic rate.

This would be consistent with previous investigations, as it well known that protective clothing can cause disproportional increases in heart rate with rises in metabolic rate, due to the dissipation of metabolic heat caused by increases in skin blood flow (Nunneley, 1989; McLellan, 2008). Indeed, the increase in thermal and cardiovascular strain when exposed to extraneous factors, such as severe heated conditions, is well established (Smith *et al.*, 1997), and in most cases, thermal load will drive heart rates towards maximal levels even when the external loads exerted on the subjects are not particularly high (Bennett *et al.*, 1993). Moreover, in field testing such extraneous factors are regularly encountered and these can alter physiological measures, for example the influence of dehydration in increasing heart rate (Saltin, 1964) or the cardiovascular burden from wearing thermal protective clothing (Sköldström, 1987). Furthermore, there are known continual increases in cardiovascular strain when performing simulated fire-fighting tasks in series (Smith *et al.*, 1996; Harvey *et al.,* 2008). These issues highlight why both heart rate and oxygen consumption data were measured simultaneously within this investigation.

In addition, increments in heart rate can be attributed to changes in task intensity and specificity. It is widely accepted increases in heart rate will rise in reasonable proportion with increments in exercise intensity (Åstrand and Ryhming, 1954). Simulations evaluated in our investigation provided good comparisons with the recent literature, suggesting these activities were performed at a high, operational intensity. For instance, Taylor *et al* (2010b) evaluated firefighters performing search and rescue simulations within a smoke filled building heated to 70ºC. Subjects reached a mean heart rate of 143 beats.min^{-1} across the simulation, spending more than half (~60%) of the time above the 75% heart rate zone. Similar responses were reflected in our results for tasks illustrated in Tables 3.5-3.14 and 3.21-3.23, suggesting the work conducted for the these tasks is qualitatively consistent with previous investigations, and a good indicator to suggest these tasks were performed at a high, real-life operational intensity (Sothmann *et al.*, 1992b). This is critical, as legally defensible (valid) physical employment standards must reflect the physical demands of the most important and difficult trade tasks (Jamnik *et al.*, 2010a and 2010b).

Notwithstanding this relationship, observations of some of the remaining trade-tasks evaluated in this study, lend support to the possibility that trade tasks quantified in parts of the literature were completed at a higher intensity. For instance, the data for the prolonged use of 38- and 70-mm hose (Table 3.23) displayed a low level of cardiovascular strain, yielding mean heart rates of 113 and 123 beats.min^{-1} respectively. In addition, firefighters spent large proportions of both simulations at 50% or below of age maximal values (Figure 3.17). These simulations were developed and managed by Fire & Rescue NSW subject-matter experts, whom ensured these tasks were performed at operational intensity. Firefighters low perceived demand of these tasks *(e.g.* use of 38-mm hose= 3.6 effort (scale 1-5); Table 2.8) were similar to the low physiological measures recorded in this investigation (Table 3.23). This lends support to the notion they are valid representations of the expected physiological demand for each task. However, given there were tasks that entail a higher physiological strain, yet possess similar body movements and muscular actions (Figure 3.10; Table 3.43), the author believes this provides good evidence for the potential exclusion of these aforementioned tasks from the construction of a final criterion trade-task list.

There are several other possible reasons for the differences in heart rate responses observed in this study to simulated fire-fighting tasks across the literature. For instance, psychological state can affect cardiac activity during exercise protocols (Carrol *et al.*, 1986), as can training status (Swain *et al.*, 1997). Moreover, emotional state can alter sympathetic drive and disproportionately elevate heart rate in relation to metabolic demand (Levenson, 1992). It was unlikely firefighters in this study were anxious, as the tasks they were performing were standardised and not unusual. However, anxiety may have influenced the results of previous investigations (Sothmann *et al.*, 1992b), where data were collected during live-fire suppression emergencies, partially explaining the high heart rates recorded.

Another crucial component of live-fire suppression is the dragging of charged fire hoses. Indeed, previous authors have evaluated the physiological demand of dragging charged fire hoses (Smith *et al.*, 1996; Williford *et al.*, 1999; Bilzon *et al.*, 2001a; Smith *et al.*, 2001; Taylor *et al.*, 2010b). For instance, Bilzon *et al* (2001a) quantified lifting and advancing a series of 12.3-m hose reels (each weighing 7.1 kg) for 4 min, resulting in a relative mean oxygen uptake of 38 $mL.kg^{-1}.min^{-1}$ (SD 5), and absolute values of 2.9 $L.min^{-1}$. This response was not reflected in our results for dragging a charged hose laterally (Table 3.23), with oxygen consumption numerically less than the work of Bilzon *et al* (2001a). However, our data does have similarities with more recent work (Taylor *et al.*, 2010b). Taylor and colleagues (2010) studied several physiological variables during five simulated search and rescue activities, one of which involved dragging a charged hose over level ground. Mean oxygen uptake in the study of Taylor *et al* (2010b) was reported at 1.29 L.min. However, given the average duration (1.42 min), it is difficult to infer the aerobic demand of this task, as an approximate steady state has not be reached (Sheppard *et al.,* 1968; Nielson *et al.*, 2010). Rather, it seems this task is more reliant on muscular strength (Table 3.43; Taylor *et al.,* 2010b) than cardiorespiratory endurance. Regardless, there existed tasks which entailed a greater load (*e.g.* hazmat task) with the same muscular action (hold and carry) in our investigation, warranting the exclusion of dragging a 70-mm hose laterally from the final criterion trade-task list (Section 3.3.4).

If an individual does not reach a steady-state, the use of cardiorespiratory variables are not always valid in defining the metabolic cost of the activity or using this metabolic cost to express the aerobic equivalent. Thus, this can influence the development of physical employment standards. For instance, minimal oxygen uptake values expressed and administered as a recruit screening test, via the attainment of aerobic equivalent of levels on the 20-m, multi-stage, shuttle-run test (Léger and Lambert, 1982), are not adequate for use if the duration from which these values were derived was less than 3 min (Sheppard *et al.*, 1968). Indeed, in our investigation there were tasks (*e.g.* stair climb with ventilation fan) with durations shorter than 3 min, highlighting the useful purpose of the hot-cell fire rescue simulation. Importantly, this was of particular interest for comparing trade tasks that exhibited high cardiorespiratory variable values, but were short in duration. If a short duration task elicited similar responses in the hot-cell fire rescue (where these tasks were performed for prolonged durations), the validity of such a task could be evaluated.

The long duration of the hot-cell fire rescue simulation (mean: 19.57 min; Table 3.42) allowed for the attainment of a steady-state. Thus, this simulation provided an opportunity to evaluate a series of tasks (hose drag, dummy drag, stair climb with charged 38-mm hose) performed in sequence that would replicate, and approximate, real-life fire-fighting scenarios. For instance, the validity of the fire attack simulation could be evaluated, since the task was also present in the hot-cell rescue simulation. Mean heart rate for this activity was similar, with mean heart rate for the fire attack 143 beats.min^{-1} (Table 3.23) and hot-cell rescue values 149 beats.min^{-1} (Table 3.42). Similarly, there was a 95% chance that the absolute oxygen consumption would fall within the zones: 1.41-1.81 (fire attack; Table 3.10) and 1.34-1.72 L.min^{-1} (hot-cell rescue; Table 3.41). This overlap lends support to the valid characterisation of the fire-attack activity. Furthermore, this activity was the only strength task that dominantly utilised a lower body push, pull, drag action (Table 3.43[5]). Moreover, this task entails a unique postural limitation and is critical in its nature, since it is the lead up activity to the rescuing of a fellow firefighter (personal communication, Fire & Rescue NSW). This lends support to the valid inclusion of the fire attack in the final

[5] Both the firefighter rescue and stair climb with fully charged 38-mm hose used both the upper and lower body to such an extent which warranted listing these activities in both of these sub-sections within Table 3.43.

criterion trade-task list (Section 3.3.4).

One can also compare the cardiorespiratory variables recorded in this hot-cell rescue simulation with the results of the other tasks utilised in this investigation. Similar results lend support to the cardiorespiratory variables in the single tasks encompassing a valid representation of the physiological demands of the task. This is especially important for some of the most physiologically demanding activities in our study, such as performing a stair climb dragging a charged 38-mm hose (Table 3.13), which was also performed as part of the hot-cell rescue. The stair climb dragging a charged 38-mm hose task resulted in a mean specific oxygen uptake of 17.81 $mL.kg^{-1}.min^{-1}$. Similar results of the hot-cell fire rescue (15.09 $mL.kg^{-1}.min^{-1}$; Table 3.41), suggest the results of the stair-climb task were an adequate representation of the expected physiological demands as performed at realistic operational intensities.

Furthermore, mean ratings of perceived exertion for the stair climb dragging a charged 38-mm hose and hot-cell rescue (ambient) were 15.4 (~ hard) and 13.1 (~ somewhat hard) respectively (Table 3.40). Previous authors report ratings of perceived exertion for advancing hoses while stair climbing at 13.4 (Smith *et al.*, 1996). These results were likely a function of the different work rates and durations of each task. The hot-cell rescue was more than five times longer and entailed more lighter intensity activities, such as unloaded travel up and down stairs, and searches on the ground floor. Furthermore, firefighters had small rest breaks when required during the hot-cell simulation. However, the stair climb with charged hose entailed work of a high intensity for the entire duration of the task. Ratings of perceived exertion were reported every 3 min for the hot-cell rescue task. Comparatively, the stair climb, due to its short duration, allowed for only one rating to be ascertained.

Simulations involving heavy load carriage and high-intensity dynamic work were perceived as the most difficult tasks. For instance, the firefighter rescue reported the highest perceived exertion (17.0; very hard; Table 3.40). High ratings of perceived exertion are common amongst previous studies evaluating rescue activities in thermoneutral and hot conditions (Eglin and Tipton, 2005), sledge axe tasks (15.6; Smith *et al.*, 1996), and those investigating the effects of heavy load carriage activities (Holewijn, 1990; Queseda *et al.*, 2000; Beekley *et al.*, 2007). These responses were reflected in our results (Table 3.40), with the sledge axe forced entry, stair climb with charged hose and ventilation fan carry up stairs all reporting a rating of 15 or higher (hard to maximal). Given these three tasks were among the top five physiologically straining tasks, with comparable heart rates and perceived ratings (Table 3.23; 3.40; Borg, 1962a), these ratings of perceived exertion were a good indication of the tasks' physiological demand (Table 3.23).

As previously mentioned, 45% (seven) of the tasks in this investigation involved load carriage of 15 kg or greater. Five of these tasks occupy the top seven ratings of perceived exertion (Table 3.40). Perceived ratings for these five tasks were approximately 35-45% numerically greater than prolonged use of 70-mm hose, dragging charged 70-mm hose, prolonged use of 38-mm hose and hose coupling (Table 3.40) tasks holding 10 kg or less (Appendix Three). Furthermore, mean heart rates for these five heavy load carriage tasks were approximately 30 beats.min^{-1} higher than lighter carriage tasks (Table 3.23). Our results are similar to previous authors, who suggest perceived ratings are greater during excessive load carriage (Myles and Saunders, 1979). These could be the product of peripheral factors (*e.g.* muscular discomfort), rather than central physiological variables, such as heart rate and oxygen consumption (Mihevic, 1981; Goslin and Rourke, 1986). However, our results do not support this reasoning with mean heart rates higher than the expected ratings of perceived exertion (Table 3.23; Table 3.40; Borg, 1962a, 1962b) for all tasks, except the firefighter rescue and stair-climbing tasks. These results support the work of previous authors (Smith *et al.*, 1996), and are likely attributable to the significant thermal load provided through the personal protective ensemble worn by firefighters, driving disproportional increases in heart rate compared with metabolic rate (Nunneley, 1989; McLellan, 2008).

Previous investigations have also reported significant increases in minute ventilation when performing load carriage activities on the back (Patton *et al.*, 1991; Stuempfle *et al.*, 2004), and with the hands (Knapik *et al.,* 2000). For instance, Knapik *et al.* (2000) quantified four different modes of load carriage, of which a two-person carry of an 80 kg dummy on a stretcher elicited the greatest cardiorespiratory stress, including minute ventilation. Furthermore, loaded exercise has shown to increase ventilation in comparison with unloaded exercise (Li *et al.*, 2003). These results support our work, with the highest minute ventilation value seen in the stair climb with fully charged 38-mm hose (Table 3.13) and the ventilation fan carry (Table 3.21). These increases are likely attributable to the effect of an increase in muscular activation due to the additional load carried (Knapik *et al.*, 1996), and the known exacerbating influence of this effect when climbing stairs (Datta and Ramanathan, 1969). This provides further evidence of the physiological demand of these tasks and lends support to their inclusion in the final criterion trade-task list (Section 3.3.4).

3.4.1.2 Cardiorespiratory-endurance activities

Previous authors have shown fire-fighting simulations require considerable cardiorespiratory endurance (Lemon and Hermiston, 1977a; O'Connell *et al.*, 1986; Bilzon *et al.*, 2001; von Heimburg *et al.*, 2006; Holmér and Gavhed, 2007). Two endurance-based fire-fighting simulations quantified and evaluated in our investigation were found to reflect meaningful levels of physiological strain (the use of a sledge axe to gain entry and dragging a 38-mm hose on uneven terrain; Figure 3.10; Table 3.43). Both these tasks were loaded activities and perceived to be physically arduous by fire-fighting subjects (Table 3.40; Appendix Three), with the greatest load utilised whilst dragging a 38-mm hose on uneven terrain (>30 kg), followed by the use of a sledge axe to gain entry (<20 kg).

For instance, using a sledge axe (4.5 kg; Appendix Three) to gain entry resulted in mean heart rate values of 165 beats.min^{-1} (Table 3.23), with one subject reaching a maximal value of 196 beats.min^{-1}, and mean absolute oxygen consumption reporting values of 1.55 L.min^{-1} (Table 3.23). These observations are consistent with previous authors who measured heart rate responses of firefighters completing a forced entry, with mean heart rates reaching 175 beats.min^{-1}, or 92% of age predicted maximal values (Williford *et al.*, 1999). Furthermore, Smith *et al* (1998) quantified the cardiovascular responses of fifteen male firefighters, chopping wood inside a training structure with mean heart rate reaching 182.3 beats.min^{-1}. In addition, ~85% of time was spent above the 75% heart rate zone for the sledge axe door entry task in our investigation (Figure 3.18). Moreover, Nwuba and Kaul (1987) compared the energy expenditure during a range of traditional Nigerian wood-cutting tools, of which the use of the heavy axe (3.97 kg) was found to elicit the greatest mean heart rate (138 beats.min^{-1}). Conclusions drawn from this suggest the weight of the tools directly influences the energy expended for its use (Nwuba and Kaul, 1987). Thus, it is critical potential fire-fighting recruits are capable of operating the equipment (external loads) required within NSW fire fighting, such as the sledge axe, as it clear these external loads will induce considerable physiological strain. With the addition of the restrictive nature of multi-layered garments, such as those used in contemporary fire fighting, performing a dynamic axe task in the personal protective ensemble used in this study would predictably elicit high heart rates.

Dragging a 38-mm hose on uneven terrain (bush drag) was the second endurance task found to elicit considerable physiological strain in our investigation (Figure 3.10; Table 3.43). Firefighters themselves consider strength endurance to be the predominant fitness classifications of fire fighting in the bush (Phillips *et al.*, 2012). These methods from Phillips *et al* (2012) focussed on bush fire suppression tasks, which entail a more prolonged duration than metropolitan and rural contemporary fire-fighting practice. Thus, these tasks would presumably require a greater cardiorespiratory component. Previous authors have quantified the cardiovascular demand of bushland fire fighting (Brotherhood *et al.*, 1997; Budd, 2001). Whilst these studies can give indications of energy expenditure, live-fire suppression makes it difficult to obtain reliable respiratory variables, and accurately compare these data with data from our investigation. Regardless, it is well established that dragging charged hoses in metropolitan areas is physiologically demanding (Smith *et al.*, 1996; Williford *et al.*, 1999; Bilzon *et al.*, 2001; Smith *et al.*, 2001; Taylor *et al.*, 2010b). Accompanied with our data, this indicates that performing a bush hose dragging task is physiologically extremely demanding, and lends support to the valid inclusion of this task in the criterion trade-task list for screening test development.

During the development of these screening tests, one must ensure the focus is upon the respective movements or physiological attributes of each task. This is critical to ensure the validity of a screening test used to identify capable and incapable recruits. Given that none of the fifteen physically demanding tasks in this study were unloaded cardiovascular tasks (Table 3.43), introducing a screening test that is reflective of this attribute (*i.e.* the 20-m, multi-stage, shuttle-run test; Léger and Lambert, 1982) would leave organisations open to legal challenges. For instance, it is well known that unloaded evaluations of cardiovascular endurance make unreliable predictors of performance when load carriage is involved (Bilzon *et al.*, 2001b; Vanderburgh, 2008). Furthermore, Fire & Rescue NSW personnel are restricted, under occupational health and safety regulations (NSW Government, 2000), from running when fully clothed in the personal protective ensemble (personal communication, Fire & Rescue NSW).

However, the current screening test used by Fire & Rescue NSW involves running (*i.e.* the 20-m, multi-stage, shuttle-run test; Léger and Lambert, 1982), and it utilised as a pre-employment screening tool to assess the aerobic power required to perform physically demanding of fire-flighting duties. This would thus seem an invalid predictor of a firefighter's ability to perform the job, given that fire fighting does not entail these characteristics. On this test the required aerobic power is represented by the attainment of a score of Level 9.4. This standard was based on findings of heart rate and oxygen uptake data on 60 firefighters performing 27 task elements (Gledhill and Jamnik 1992a). Mean relative oxygen uptake for climbing flights of stairs whilst dragging (advancing) a charged hose and carrying a halligan tool was 44 $mL.kg^{-1}.min^{-1}$, and the researchers further recommended that a standard of 45 $mL.kg^{-1}.min^{-1}$ be maintained by all active firefighters (Gledhill and Jamnik 1992a). Furthermore, for the next 15 years this standard was accepted by fire-fighting organisations around the world including provinces within North America, Great Britain and Australia.

Moreover, the relative oxygen uptake values from Gledhill and Jamnik (1992a) did not account for the range of protective gear that the firefighters wore on their person during the simulations. For instance, the relative oxygen uptake values in our investigation were divided by total nude body mass plus mass of the personal protective equipment (mean total mass 108.71 kg in this investigation), whilst the values from Gledhill and Jamnik (1992a) were derived solely from body mass, and did not account for personal protective equipment. While it is argued the body is the only active component and any additional load could hinder comparisons of metabolic cost between activities (personal communication, Gledhill, 2012), metabolic rate is absolutely both a function of the total load and the size of the active muscles. Thus, any additional load being worn would affect the rate of oxygen consumed during an occupational task, proving that the values derived from these studies, are overestimations of the cardiorespiratory requirements for firefighters.

Thus, it could be argued that oxygen uptake values used for setting minimum physical employment standards be reported in absolute terms. Relative measures of oxygen uptake have been shown to be valid when analysing repetitive workplace activities, such as stair climbing (Jackson *et al.*, 1995; Jackson *et al.*, 1996). However, a relative standard disadvantages larger individuals (Vanderburgh, 2011). An absolute standard would therefore give a more valid test as it does not imply a body mass bias, especially for repeated manual handling tasks (Sothmann *et al.*, 1990), such as those experienced in fire fighting. While relative measures of oxygen uptake assist in the understanding of the variability in individuals' absolute oxygen consumption for both resting and exercising states, absolute measures may give a clearer indication of the minimum requirement for the completion of several physically demanding tasks.

An example of these relative measure disadvantages is in the military. Given the employment benefits (*e.g.* promotion) of greater performance levels in physical military tasks, there is justification in the suggestion that lighter individuals have an advantage in the performance scores reflective of fitness task performance due to the overcompensation for body mass (Vanderburgh and Mahar, 1995; Dooman and Vanderburgh, 2000; Vanderburgh, 2008). These instances can lead to invalid associations regarding physical performance (Heil, 1997; Vanderburgh and Batterham, 1999). For instance, if an invalid cardiorespiratory measure was established and administered as a set level on the shuttle run, or the time to complete a pre-recruitment circuit, potential recruits may unfairly fail the screening test. Thus, the test would constitute the failure to recruit potentially good firefighters, those capable of performing physically demanding duties but are not passing the pre-employment screening test. Given task-specific tests cannot bias individuals (Vanderburgh *et al.*, 2011), organisations are open to legal action on the basis of discriminatory practice involved in the process of standard development and implementation if bias occurs (Constable and Palmer, 2000; Gledhill *et al.*, 2001; Doherty *et al.*, 2007).

For instance, Meiorin, a female firefighter, was dismissed by her employer after three years of service, due to her inability to meet a newly introduced eight-minute aerobic fitness standard. Meiorin argued that the standard was discriminatory based on gender (Supreme Court of Canada, 1999). This eight-minute standard was established using fit, healthy young men, thus the time to complete the task was fairly quick. The Supreme Court established that while the standard was developed in good faith for the effective performance of the job, the employer had failed to demonstrate that the standard was necessary to the accomplishment of the task. Thus, the standard created did not establish the minimum requirement to complete the task, rather the requirement of fit, young men to complete the task. Therefore, an employer must be able to demonstrate that the fitness screening requirements implemented are necessary for the accomplishment of the adequate performance of the job. This research will potentially facilitate the establishment of valid and legally defensible screening tests for use during recruit selection.

Thus, it would seem, that the current 20-m shuttle run currently in place to recruit firefighters in this State be replaced by a test that better reflects the demands of contemporary fire fighting. When load carriage is an important occupational constraint, then one must evaluate physiological function under loaded situations (Vanderburgh and Flanagan, 2000; Bilzon *et al.*, 2001b; Vanderburgh, 2008; Vanderburgh *et al.*, 2011). Indeed, 45% (seven) of the tasks in this investigation involved load carriage of 15 kg or greater (Appendix Three). Furthermore, there is good evidence to suggest that load carriage is the primary effector of an increase in heart rate under controlled conditions (Duncan *et al.*, 1979; Louhevaara *et al.,* 1985; Lloyd and Cook, 2000). Differences in external loading in the form of clothing, or additional equipment carried on firefighters, vary across the literature, however generally they are reported ~20 kg (Taylor *et al.*, 2010a), but can be heavier in certain provinces within the United States (26.2 kg; Smith *et al.*, 2001), and even more so in Scandinavian countries, where this mass can reach upwards of 30 kg (Sköldström, 1987). Thus, it is recommended Fire & Rescue NSW include screening tests that induce considerable physiological strain under loaded states.

The eventual aim of this project was to facilitate the identification of predictive screening tools that will potentially increase worker capability and minimise risk of injury of firefighters. Predictive screening tools with a high sensitivity are sought, that as such they inherently become more reliable (providing reproducible outcomes) and valid (providing predictions of job performance). This reduces variability between job performance and the pre-employment screening test, maximising true positives and true negatives while minimising the number of false positive and false negatives. By analysing the results of the distillation process in filtering occupational tasks (Table 3.43), one can investigate the similarities between trade tasks in regards to their respective movements or physiological attributes.

Given the high occurrence of strength and muscular-endurance tasks, it is highly recommended these activities be analysed further to determine whether shared common movement characteristics and physiological attributes exist between simpler tasks of a similar nature. If such tasks do indeed share these correlations, these tasks can be distilled and filtered into possible screening tests. Due to the existing limitations within the development of task-specific assessments for potential firefighters (*e.g.* personal safety, financial burden, skill), it is important to investigate, where applicable, alternative approaches to the mere duplication or simulation of critical fire-fighting tasks. This is the aim of, and is studied further in, the final study of this dissertation (Chapter Four).

3.5 CONCLUSION

This study evaluated and quantified each of the fifteen essential, physically demanding trade tasks to determine the physical and physiological attributes necessary to perform these fire-fighting duties in an optimal and safe manner. On the basis of these analyses and a filtration process, which culled tasks to minimise the duplication of movement patterns and loads within this sub-set of tasks, a list of eleven criterion fire-fighting tasks was grouped into four activity classes, which possess similar physical and physiological attributes. These may be used to develop screening tests that could be used to identify capable and robust potential fire-fighting recruits. It is proposed that if a firefighter is able to successfully perform activities within each class in the criterion trade-task list, they will possess the minimum physical and physiological attributes to perform contemporary fire-fighting duties, as performed in NSW, in a safe and efficient manner. Indeed, it is recommended these activity classes be distilled further and task constraints analysed. Thus, further investigation and breakdown of the critical elements of these trade tasks can be conducted, and this is the aim of Chapter Four. This will assist in the development of a preliminary format for firefighter assessments.

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CHAPTER 4: PHYSIOLOGICAL SCREENING TESTS FOR CONTEMPORARY FIREFIGHTERS

4.1 INTRODUCTION

Since fire fighting is recognised as an extremely physically demanding occupation (Davis *et al.*, 1982; Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001a; Barr *et al.,* 2010), fire-fighting organisations have a legal obligation to recruit individuals who are capable of tolerating the demands of this profession (Constable and Palmer, 2000; Jamnik, 2010a). Given the high injury rates of firefighters within New South Wales (170.5 injuries per 1,000 full time firefighters per annum (Taylor and Kerry, 2010)), there also exists a necessity to identify less capable individuals. These individuals must be identified as they would be exposed to an unacceptable risk of injury during the performance of various fire-fighting roles. Pre-employment physiological screening tests can serve to identify both capable and incapable individuals. These tests aim to simultaneously increase the capability of the workforce whilst minimising the risk of injuries to both firefighters and members of the community. Moreover, capable employees are clearly associated with fewer injuries in fire fighting (Cady *et al.*, 1985) and other manual handling occupations (Chaffin, 1974), such as the Navy (Marcinik, 1986).

Nevertheless, the employer must also ensure that no individuals, or groups of individuals within society, are discriminated against or treated less favourably when developing these screening tests (Anti-Discrimination Act, 1977; Constable and Palmer, 2000; Jamnik *et al.*, 2010a and b). The critical legal and scientific steps within developing physical employment standards have been established (Table 1.1), and these steps provided the framework for the current project. By identifying the essential, demanding tasks of fire fighting (Chapter Two) and quantifying the physiological demands (Chapter Three) of these tasks as performed within NSW, the development of legally defensible task-specific assessments for potential firefighters can be conducted (Gledhill *et al.*, 2001). Thus, the purpose of this investigation is to develop legally defensible (valid) physiological screening tests for firefighters. Such an approach will assist in the identification of recruits who are capable of tolerating the physiological strain associated with fire fighting. These recruits will be well suited to undertake fire-fighting tasks in a safe and productive manner. In addition, this process must ensure that the full demands of fire fighting are adequately represented in the provision of valid screening tests that have a predictive capacity for fire-fighting performance.

Nevertheless, there are key limitations that exist within this process. Firstly, physiological screening tests can have a detrimental financial impact on the employer. For instance, environmental and equipment constraints mean screening tests can be expensive to administer. The additional cost of transporting equipment to different test locations can place a significant financial burden on the organisation. Secondly, personal safety must be carefully considered. For example, highly motivated participants are more likely to injure themselves during testing (Ayoub, 1982) due to the high reward for passing a screening test (*i.e.* employment). Furthermore, injures are common when these tests comprise high-capacity, manual-handling tasks (Snook *et al.*, 1978). Thirdly, consideration must be given to the level of skill included within screening tests (Equal Employment Opportunity, 1978; Constable and Palmer, 2000). This is especially crucial in examining the degree to which the skill dictates the successful completion of the fire-fighting task, regardless of whether these tasks include numerous elements of skill or not. With this in mind, physiological screening tests should primarily target physiological attributes that can be evaluated independently of skill or task performance proficiency. Given firefighter specific skills form a critical part of training (personal communication, Fire & Rescue NSW), these skills can be taught after recruitment.

Thus, if applicable, alternate approaches to the simulation or duplication of fire-fighting tasks must be sought. For instance, when a strong relationship between a critical work task (*e.g.* carrying a ventilation fan) and a basic physical test (*e.g.* grip-strength test) exists (Sharp *et al.*, 1993a; Kraemer *et al.*, 2001), such a generic test can be used to predict occupational task performance, as it possesses criterion validity (Equal Employment Opportunity, 1978). Criterion validity ensures test analyses can accurately compare outcome (generic experimental) measures with an established criterion reference (known occupational demand; Taylor and Groeller, 2003). Furthermore, administering a basic physical test (*e.g.* grip-strength test) may alleviate limitations of test administration as they are inexpensive and do not involve a high degree of skill.

It is common for critical tasks within physically demanding occupations to share similar movement characteristics and physiological attributes (Gledhill and Jamnik, 1992a; Constable and Palmer, 2000; Chapter Three). By classifying such tasks into separate classes (groupings) that are representative of these characteristics, correlations between these tasks can be investigated. Potentially, this allows these tasks to be distilled and developed into possible physiological screening tests. Herein lies the purpose of this investigation.

4.1.1 Aims of this study

The aim of this study was to develop a wide range of physical tests that, in combination, would be representative of a legally defensible physiological screening test for firefighters. Firstly, the eleven criterion tasks identified in Chapter Three were analysed, and excluded if necessary, to increase screening test efficiency. Secondly, constraints, limitations and considerations were identified for all remaining criterion tasks. Following this, a preliminary format for firefighter assessments (physiological screening test) was developed, from which a successful recruit would possess the minimal physiological attributes desired of a contemporary firefighter. In addition, recommendations were put forward to explore possible existing inter-relationships among the remaining criterion tasks.

4.2 DEVELOPMENT OF A VALID PHYSIOLOGICAL SCREENING TEST

To ensure the development of a valid physiological screening test, the process conducted within this investigation followed the flow chart illustrated in Figure 4.1a and b. This method aimed to develop a physiological screening test without compromising either the legal defensibility, sensitivity or specificity of the proposed employment standard. Indeed, if such a method was followed, the identification of true positive (suitable) and true negative (unsuitable) individuals would potentially be maximised during recruit screening. Furthermore, this process would minimise the number of unsuitable recruits chosen, and the number of suitable candidates who might be rejected.

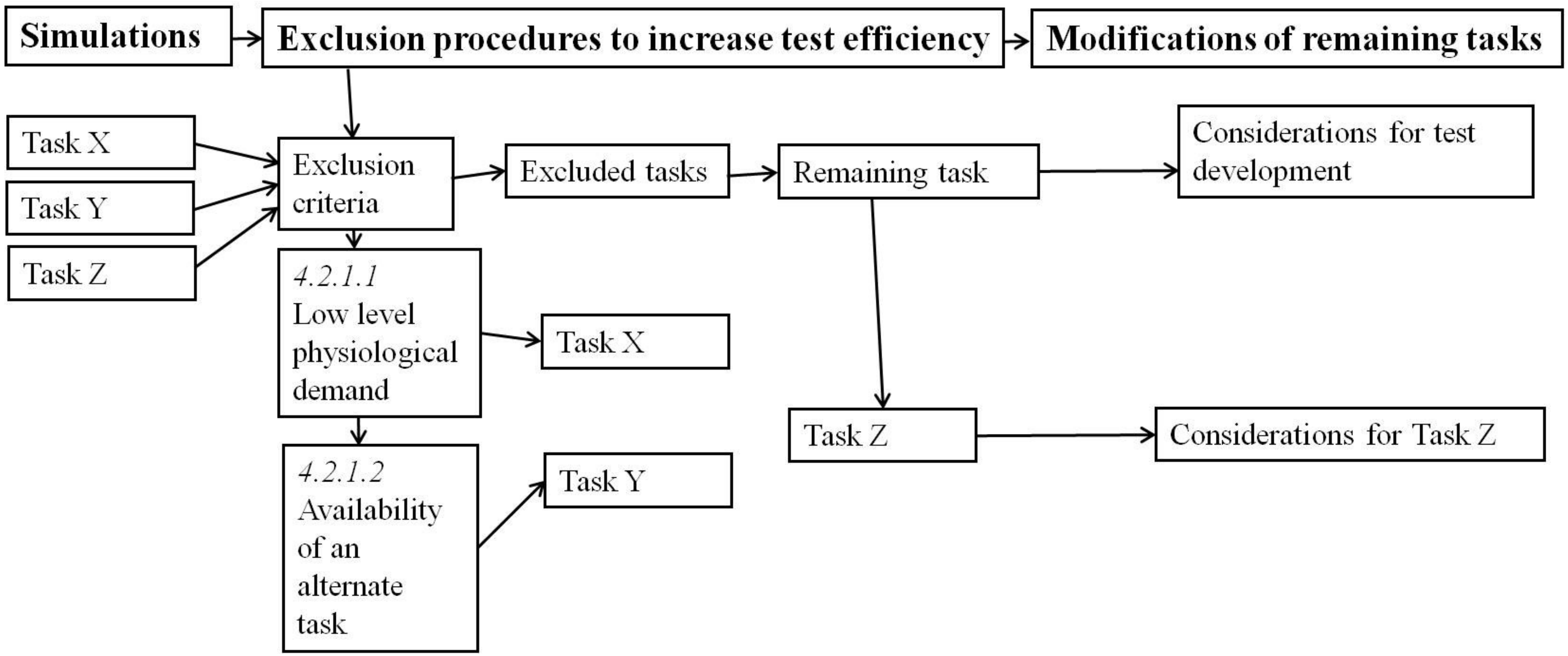

Figure 4.1a: Flow chart for the development of a physiological firefighter screening test. All criterion task simulations identified in Chapter Three (Section 3.3.4) were put through exclusion criteria. Tasks X, Y and Z are hypothetical criterion tasks. Exclusion criteria numbers correspond to the numbered sections within this dissertation. When tasks met the respective exclusion criteria, they were excluded (Tasks X and Y). When a criterion task remained (Task Z), test development considerations were evaluated for the respective task.

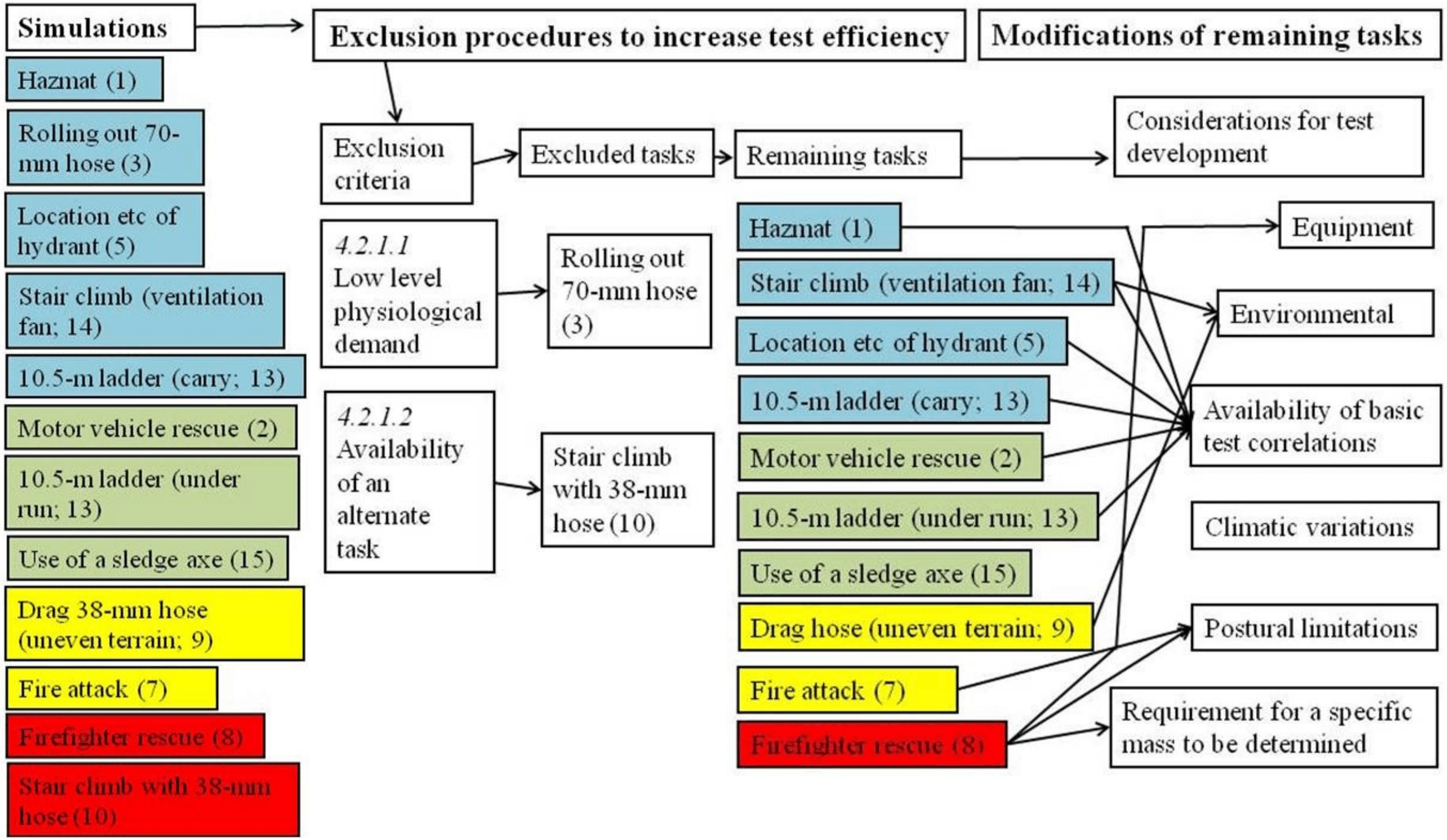

Figure 4.1b: Flow chart for the development of a physiological firefighter screening test encompassing the criterion task simulations identified in Chapter Three (Section 3.3.4). Colours indicate the tasks within their respective criterion task classifications (grouped on similar muscular movements and actions) one through to four (section 3.3.4). Class one: light blue; two: light green; three: yellow; four: red. Exclusion criteria numbers correspond to the numbered sections within this dissertation.

Since it would be inefficient to consider using all eleven criterion tasks identified in Chapter Three within a physiological screening test for firefighters (personal communication, Fire & Rescue NSW), we firstly excluded tasks to assess if efficiencies could be gained within this process. This was a collaborative approach, with input being sought from members of the Research Team and a member from the Project Management Team during a meeting at the university (Appendix Five). This collaborative approach was crucial, as these members provided expertise which was necessary to determine adequate criterion task suitability and administration. In particular, the member of the Project Management Team was responsible for informing the author and the Research Team of the Fire & Rescue NSW operational constraints that would influence test selection, design and implementation. This approach determined the suitability of each task within a firefighter-specific screening test. On the bases of these analyses, a preliminary format for firefighter assessments was developed. The following text provides evidence for the decisions and considerations made at each step within this process (Figure 4.1a and b).

4.2.1 Excluding criterion fire-fighting tasks for physiological screening test efficiency

Administering a physiological screening test comprising eleven criterion tasks would be inefficient and impractical (personal communication, Fire & Rescue NSW). Thus, exclusion criteria were developed to determine whether or not a criterion task could be validly eliminated without compromising either the legal defensibility, sensitivity or specificity of the proposed employment standard. Culling such tasks would be advantageous and increase test efficiency, as there were common movement patterns within the criterion fire-fighting tasks identified in Chapter Three (Section 3.3.4). To identify these duplications, each of the eleven criterion tasks were classified into one of four different movement categories. These classifications are presented in Table 4.1[6]. All tasks were then subject to exclusion. A task was eliminated when comparisons between tasks contained a low relative, whole-body physiological demand or the presence of a suitable task alternative. If a task satisfied either of these criteria, it was considered for elimination.

[6] During this phase of research, it was decided to sub-divide the ladder task into two parts (carrying and under-running) as it was considered this task fell within two different movement classes.

Table 4.1: Criterion task movement classifications.

Criterion task class	Class description	Criterion tasks
1	Single-sided carrying tasks	Hazmat task
		Rolling out hose (70 mm)
		Locating and connecting to hydrant
		Ladder carriage (10.5 m)
		Stair climb with ventilation fan
2	Overhead push/holding tasks	Motor-vehicle rescue
		Ladder under-run (10.5 m)
		Using a sledge axe to gain entry
3	Cardiorespiratory dragging tasks	Fire attack
		Dragging charged hose (38 mm)
4	Critical strength task	Stair climb with charged hose
		Firefighter down - rescue

4.2.1.1 Exclusion criteria: Low-level physiological demand

One task was eliminated from further consideration (rolling out 70-mm hose) on the basis of a low-level physiological demand (Figure 4.1a and b). The average task heart rate (144 beats.min^{-1}) and absolute oxygen consumption (1.58 L.min^{-1}) were similar to values observed during other physically demanding tasks (Tables 3.23). However, feedback of focus groups and the low ratings of perceived exertion (mean 11.6: Table 3.45), indicate firefighters do not consider rolling out a 70-mm hose to be overly difficult or physiologically demanding. On the premise of this exclusion criterion (low-level physiological demand), this task was recommended for elimination. Furthermore, since these tasks shared common movement patterns and characteristics with the ladder-use and the hazmat tasks, this lends support to the valid exclusion of this task.

4.2.1.2 Exclusion criteria: Availability of an alternative task

Where tasks shared similar movement patterns and characteristics, but different durations or loads, a suitable substitution task was investigated. For example, if a task entailed a similar movement pattern to another criterion task, but the load carried was heavier, or the task duration longer, the task with the lesser load or shorter duration (the easier task) was considered for elimination. A task considered for elimination in accordance with this exclusion criterion was the stair climb (dragging a charged 38-mm hose) task (Figure 4.1a and b). This task possessed whole-body strength (both upper and lower), characteristics similar to that of the firefighter rescue (Table 4.1). There are also similarities in movement patterns across both tasks. Thus, if an individual could perform the task with a greater load (firefighter rescue), then this person could be deemed to be capable of performing a task with a lighter load (stair climb with a charged 38-mm hose). The firefighter rescue was also a more critical activity, thus it was recommended the stair climb with a charged 38-mm hose could be eliminated on the basis of task substitution.

Since the stair climb with a charged 38-mm hose entails a significant vertical component and elicited the greatest mean oxygen consumption in Chapter Three (Table 3.23), eliminating this task purely on the availability of an alternative task would presumably raise concern. However, the loaded vertical displacement component of this stair-climb task would also be observed within the stair climb (carrying the ventilation fan), which also possessed a similar lower-body strength requirement. Furthermore, the strong cardiorespiratory requirement to perform the stair climb with a charged 38-mm hose (1.97 $L.min^{-1}$; Table 3.23) could be elicited through the cumulative effect of performing a screening test in series, providing the mean oxygen consumption required to complete this test is similar to the values expressed for the stair climb with a charged 38-mm hose. Thus, we believe this lends support to the valid exclusion of the stair climb (whilst dragging a charged 38-mm hose) from the final criterion task list. However, given this exclusion, it is important to develop a firefighter physiological screening test with a strong cardiorespiratory requirement, and it is suggested this be done through the performance of multiple criterion tasks in series. Indeed, this has been validated throughout the literature for other emergency service and military occupations (Considine *et al.*, 1976; Brownlie *et al.*, 1985; Taylor *et al.*, 2003 Jamnik *et al.*, 2010a and 2010b).

4.2.2 Modifications of remaining tasks: Analysis of remaining criterion tasks with respect to the operational constraints and limitations that exist within the State

With these exclusion processes complete, the remaining tasks which form the base for the physiological screening test are illustrated in Table 4.2. Aside from the excluded tasks, the only change from Table 4.1 was a re-classification of the fire attack. The fire attack is a critical lead up activity to the firefighter rescue. Since the fire attack also ascertains a postural limitation and dragging a charged 38-mm hose does not (personal communication, Fire & Rescue NSW), the separation between dragging a charged 38-mm hose over uneven terrain and the fire attack within the cardiorespiratory drag class was deemed necessary at this phase of research. We conclude that if a firefighter is able to successfully perform activities within each class in Table 4.2, they will possess the minimum physical and physiological attributes to perform contemporary fire-fighting duties, as performed in NSW, in a safe and efficient manner.

Give the importance of reflecting the necessary physical and physiological attributes within a pre-employment screening test (Jamnik *et al.*, 2010a and b), the following text provides evidence of why each criterion class is necessary for inclusion within a proposed

Table 4.2: Remaining criterion tasks for the physiological screening test.

Criterion task class	Class description	Criterion tasks
1	Single-sided carrying tasks	Hazmat task
		Locating and connecting to hydrant
		Ladder carriage (10.5 m)
		Stair climb with ventilation fan
2	Overhead push/holding tasks	Motor-vehicle rescue
		Ladder under-run (10.5 m)
		Using a sledge axe to gain entry
3	Cardiorespiratory drag task	Dragging charged hose (38 mm)
4	Critical task	Fire attack
5	Critical strength task	Firefighter down - rescue

physiological screening test for NSW firefighters. These physiological screening tests would likely be administered at numerous testing sites throughout NSW (personal communication, Fire & Rescue NSW). However, it was apparent that administering a physiological screening test across NSW would be challenging, given the operational constraints and limitations that exist within the State (Figure 4.1b). For instance, the lack of constant access to stairs was a potential issue since the stair-climb with a ventilation fan was one of the remaining criterion tasks (Table 4.2; personal communication, Fire & Rescue NSW). Thus, constraints and limitations were also analysed, where applicable, for each criterion class. This involved the identification of important limitations that may affect the operational implementation of the test, the test design or selection and were carefully considered when determining the suitability of any criterion fire-fighting task for inclusion within a physiological screening test for firefighters. The completion of this process would ensure all aspects of test administration were considered during the final development of the proposed physiological screening test. Indeed, this process would aim for the developed test to be easily administered across New South Wales, and without the need for extensive equipment or personnel.

4.2.2.1 Single-sided carriage tasks

The inclusion of a single-sided unilateral carriage task class for utilisation within the proposed physiological screening test was recommended. The detrimental presence of load carriage within physically demanding occupations is well established (Gledhill and Jamnik, 1992a; Bilzon *et al.*, 2001b; Taylor *et al.*, 2003; Milligan *et al.*, 2010). One-handed (unilateral) load carriage tasks have been proven to be physiologically demanding (Table 3.23; Milligan *et al.*, 2010), and can lead to cardiovascular and muscular fatigue (Genaidy *et al.*, 1989; Kilbom *et al.*, 1992; Dennison *et al.,* 2012). Holmér and Gavhed (2007) evaluated the physiological responses of male, professional firefighters to simulated work tasks. For tasks entailing load-carriage characteristics, absolute mean oxygen uptake can approach 3.0 $L.min^{-1}$ (Holmér and Gavhed, 2007). Single-sided load carriage tasks quantified in Chapter Three of our project, such as the hazmat task, 10.5-m ladder carry, stair climb with ventilation fan and the location and connection of a fire hydrant, did not reach such values but still resulted in considerable physiological strain (1.61 $L.min^{-1}$, 1.44

L.min^{-1}, 1.49 L.min^{-1} and 1.56 L.min^{-1} respectively). Furthermore, all four tasks fell within the top ten highest mean oxygen consumption values (Table 3.23) of the fifteen essential, physically demanding trade tasks.

Perhaps more importantly, 75% of the six heaviest loads used within this investigation were involved with the four single-sided unilateral carriage tasks (Appendix Three). Since the unilateral carriage of a load was so prevalent (four criterion tasks) within the nine remaining criterion fire-fighting tasks (Table 4.2), and the high physiological demand (Gledhill and Jamnik, 1992a; Constable and Palmer, 2000) associated with these tasks (Table 3.23), we believe the inclusion of a single-sided unilateral carriage task for utilisation within the proposed physiological screening test is necessary for these standards to be legally defensible (Gledhill *et al.*, 2001).

Three of the tasks involving unilateral carriage required two people to complete the task (stair climb with ventilation fan, hazmat and 10.5-m ladder use). To make comparisons of load-carriage tasks that required more than one person, it was assumed that the load was equally distributed between the firefighters. For the purpose of this analysis, this was deemed an acceptable measure, however the degree to which this dictates the inclusion and exclusion of tasks was carefully considered. For instance, in the military, occupational standards have been known to double the maximum load lifted by an individual for two person (team) lifts (Military Standard 1472 U.S., 1989). However, the sum of individual lifting strength has been reported to exceed team lifting strength (Karwoski and Mital, 1986; Karowski and Pongpatatnasuegsa, 1988; Sharp *et al.*, 1993b). This implies the allocation of a uniform load distribution for paired lifts is simplistic. Relative loads held by individuals in team lifts vary according to both the characteristics of the object that is lifted and the persons performing the lift. Such a factor could include the individual's stature.

Fire & Rescue NSW indicated the physiological screening test would need to be conducted on a standardised flat terrain given the lack of consistent access to stairs across the State. This environmental constraint (Figure 4.1b) was a concern, considering the stair climb with ventilation fan was evident within the remaining criterion trade-task list (Table 4.2). If the proposed physiological screening test retains this stair-climbing task, the validity and reproducibility of the test could be negatively affected. Thus, we concluded it was necessary to consider suitable task alternatives for this criterion task (Figure 4.1b). Thus, predictive correlations between the relative performance of stair-climbing tasks and tasks conducted on flat terrain need to be established. Indeed, these correlations have been found in previous investigations.

For instance, stair-climbing ability and six minute walk time (flat ground) have been demonstrated to possess similar accuracy and sensitivity in predicting maximal oxygen consumption (Cateneo *et al.*, 2010). Cateneo *et al* (2010) used 51 subjects performing a range of accessible testing items to determine which best predicts surgical risk. Stair climbing ability and six minute walk time were found to be the best predictors (Cateneo *et al.*, 2010). Moreover, significant correlations exist between stair-climbing speed and maximal oxygen consumption, as measured by cycle ergometry (Koegelenberg *et al.*, 2008). These correlations provide evidence that load carriage up stairs may be predicted from flat-terrain carriage tasks. Indeed, an investigation of the ability of flat-terrain carriage tasks to predict load carriage up stairs would benefit the administration of the proposed physiological screening test, as access to stairs would not be required.

4.2.2.2 Push and holding tasks

Push and holding tasks are consistent with those chosen for use in physiological screening throughout the literature. For instance, Gledhill and Jamnik (1992b) recommended the un-timed assessment of a ladder lift and place, similar to the use of a 10.5-m ladder (lift and under-run) with our study. Furthermore, Rayson *et al.*, (2004) recommended various load carriage activities, such as a ladder lift, be utilised in assessing a firefighter's capability to perform physically demanding tasks prior to entry (employment). Indeed, ladder tasks induce considerable physiological strain (Table 3.23; Gledhill and Jamnik, 1992a). Under running the 10.5-m ladder in our investigation also requires holding the load above shoulder height in an upright posture. When maximal lifting tasks require lifts to heights above the shoulder, the maximal load that can be successfully lifted is significantly lower (Mital, 1984). Given the uniqueness of these muscular positions and the heavy mass of the ladder (49.5 kg; Appendix Three), we believe the ladder under run is a critical task for inclusion in the proposed physiological screening test. The inclusion of such an occupationally specific task in the proposed physiological screening test is ideal for physically demanding organisations (*e.g.* Fire & Rescue NSW), legal arbitrators and employees, as such tasks have high face and content validity (Gledhill *et al.*, 2001).

The motor-vehicle rescue task was part of the overhead push and holding class (Table 4.2). The physiological demand of this rescue task are well established (Table 3.23; Gledhill and Jamnik, 1992a). More importantly, the muscular endurance and strength (Table 3.25) required to perform this task at different heights (range: close to the ground to above the shoulder) places a considerable strain on firefighters working musculature (Gledhill and Jamnik, 1992a). Firefighters reported tasks involving activities above the shoulder, such as the ladder under run and motor-vehicle rescue, as difficult and awkward to perform (focus groups, Chapter Two). This supports previous work on the mechanical loading of the body (Ayoub *et al.*, 1979; Warwick *et al.*, 1980; Mital, 1984; Ljunberg *et al.*, 1989). For instance, the maximal load that can be successfully lifted is significantly lower when performing maximal lifts to a height above the shoulder (Ayoub *et al.*, 1979; Mital, 1984). This is due to the changes in lever length and stability when performing in movement ranges where strength is lower (Warwick *et al.*, 1980). This could explain the high prevalence of injuries in manual handling tasks with numerous lifting activities, especially those lasting for prolonged durations and entailing awkward work postures (Ljunberg *et al.*, 1989). Since none of the nine criterion tasks which possess similar muscular actions and movement classifications entail lighter loads than the motor-vehicle rescue (Appendix Three), the motor-vehicle rescue is a necessary inclusion in the proposed physiological screening test. This is primarily due to the unique strength and muscular endurance requirements (Table 3.43) and the posture of the participant when exerting force.

While replication of the motor-vehicle rescue within a screening test would maintain high face validity, we were concerned excessive twisting and turning of the trunk under load (19.5 kg) would result in injury for untrained recruits. There may be an increased likelihood of injury for highly motivated participants, given the benefits of passing a screening test (*e.g.* employment; Ayoub, 1982). Furthermore, injury risk is prevalent if these tests include high-capacity, manual handling tasks (Snook *et al.*, 1978). In addition, using the actual spreaders and shears (motor-vehicle rescue task) within the screening test would require the transportation of spreaders and shears around the State. This would not be viable (personal communication, Fire & Rescue NSW; Figure 4.1b). Therefore, to overcome this limitation and to enhance the efficiency of administering the physiological screening test, an investigation of an alternative to the use of spreaders and shears at a range of fixed heights was explored.

Following analysis of both single-sided carriage and push and holding tasks, a closer examination of dragging a charged 38-mm hose over uneven terrain, the fire attack and the firefighter rescue was conducted. A common primary movement pattern between each of these three tasks is dragging. One could argue that one or more of these tasks could be culled on the basis of movement duplication, as they possess similar muscular movements and actions (Table 3.43). This would result in only the most physiologically demanding task (firefighter rescue; Table 3.23) being retained. However, the prolonged duration of the hose drag (mean 52 min; Table 3.23), and the critical and mandatory nature of the fire attack and the firefighter rescue tasks, indicate all three criterion tasks were required for further assessment.

4.2.2.3 Cardiorespiratory drag task

A simulated cardiorespiratory 38-mm hose drag is recommended to be performed in the proposed physiological screening test. This task was chosen primarily based on its high physiological demands (Table 3.23). This is consistent with previous work highlighting the high physiological strain involved when performing hose drag tasks (Gledhill and Jamnik, 1992a; Smith *et al.*, 1996; Williford *et al.*, 1999; Bilzon *et al.*, 2001a; Smith *et al.*, 2001; Taylor *et al.*, 2010b). Moreover, Canadian, British and North American fire-fighting organisations recommend simulated hose tasks be utilised in firefighter fitness assessments (Gledhill and Jamnik, 1992b; Rayson *et al.*, 2004; Michaelides *et al.*, 2008). These results are similar to the results in this investigation (Table 4.2). This further highlights dragging a charged 38-mm hose is a unique and critical component of fire suppression (focus groups, Chapter Two). Indeed, dragging a charged 38-mm hose over uneven terrain was the most physiologically demanding loaded-cardiorespiratory endurance task in this project (Table 3.43). It was also the longest (52 min; Table 3.23). Since screening tests should reflect the most demanding trade tasks of the occupation (Gledhill and Jamnik, 1992a; Constable and Palmer, 2000; Jamnik *et al.*, 2010a and b), this lends support to the inclusion of this task within the proposed physiological screening test.

It was suggested that local sporting fields may be a suitable venue for the proposed physiological screening test to be administered. For instance, level grass fields or oval maintained and accessible through a local council or a sporting body could be used. However, consistent access to a flat open space throughout each region or station in NSW was unlikely, making it difficult to administer a valid and reproducible cardiorespiratory drag task throughout NSW, as a difference in surface will affect frictional load. Thus, if alternative equipment (Figure 4.1b) could alleviate these differences in frictional load, it is recommended such investigations be pursued.

4.2.2.4 Fire attack and fire fighter rescue

The fourth class of the physiological screening test proposes the performance of a simulated fire attack task. This task was chosen due to its criticality, high physiological demand and its face validity. The criticality and face validity of the fire attack is primarily due to its utilisation as the lead up activity to the rescuing of a fellow firefighter (personal communication, Fire & Rescue NSW). Given these tasks were so similar in nature, it was decided to analyse the fire attack both individually and simultaneously with the firefighter rescue. The inclusion of such critical, lifesaving tasks in proposed physiological screening tests is necessary to maintain the welfare of employees and members of the wider community. Furthermore, the inclusion of lifesaving tasks in screening tests is common in other emergency occupations, such as life guarding (Reilly *et al.*, 2006a and b).

Proceeding the fire attack, the simulated firefighter rescue will be performed. This task was seen as a necessary component of the proposed physiological screening test due to its high criticality, mandatory nature and heavy load (Table 3.31). The high physiological and muscular strain experienced when rescuing a fellow firefighter or a victim is well known (Davis *et al.*, 1982; Gledhill and Jamnik, 1992a; Michaelides *et al.*, 2008; Taylor *et al.*, 2010b; Chapter Three). It was also established in Chapter Two that firefighters would change their behaviour while performing tasks at an incident if they felt their partner could not drag them to safety (focus groups, Fire & Rescue NSW). Thus, the firefighter rescue is an important and critical task for NSW firefighters, lending support to its inclusion in the proposed physiological screening test. This is crucial, as legally defensible (valid) screening procedures must also reflect the physical demands of the most important trade tasks (Gumieniak *et al.*, 2011).

Both the fire attack and firefighter rescue entail a postural limitation (personal communication, Fire & Rescue NSW). This is important to recognise, as legally defensible physical employment standards must represent the standard operating procedures as imposed by the respective organisations (Gumieniak *et al.,* 2011). This postural limitation requires firefighters to operate within a constrained height (neutral zone), forcing employees to make an accommodating adjustment with their posture. Such adjustments to stay within this neutral zone are critical, as air temperature, pressure and radiant heat transfer are greater at heights above this zone (Hartin, 2009). Thus, a failure to make an accommodating adjustment with their posture would expose firefighters to excessive heat and smoke. Therefore, we recommend that within the physiological screening test a vertical height limitation be implemented for the fire attack and firefighter rescue. Such a height limitation could be easily and consistently applied within a test battery, through the use of vertical markers or horizontal lines set at the estimated height of a neutral zone.

However, the height of the neutral zone will vary dependant on the intensity and temperature of the fire, prevalence of gases in the surrounding atmosphere and the height of the room or surroundings (Hartin, 2009). The height of the neutral zone in the proposed physiological screening test would be the same across all screening tests regardless of the location. Given the difficulty in estimating the average height of a neutral zone and the absence of any statistical information regarding this height, it is recommended that this height be set by the Project Management Team (Fire & Rescue NSW). The Project

Management Team should conduct a process which includes the collection of reliable and objective data regarding the height of this neutral zone to maximise legal defensibility.

Equipment development for the physiological screening test

Several constraints on the development of the physiological screening test were imposed by equipment. As previously mentioned, dragging a charged 38-mm hose (within the cardiorespiratory drag and fire attack tasks) or a dummy (firefighter rescue) over a consistent surface and distance seemed impractical for administering the test around the State. In addition, access to laboratory-based test items was very limited as the physiological screening test needed to be deployed throughout the State and a requirement of plentiful equipment would reduce the functional capability of Fire Stations. Thus, it was concluded the test require minimal equipment. The requirement of minimal equipment would help alleviate a significant manual-handling stress on the assessor, who need not require specific medical or exercise physiology qualifications. Therefore, to overcome the various constraints imposed by fire-fighting equipment, two simulated equipment alternatives were suggested.

The first of these simulated equipment alternatives investigated was a weighted sled. It was proposed the sled would be 1 to 1.5 metres in length and permit the addition of mass to the structure. Thus, drag load could be easily varied to simulate the drag loads within the three dragging criterion tasks (dragging a charged hose across uneven terrain, fire attack and firefighter rescue). Furthermore, such devices are commonly used within a sports training setting and are commercially available. However, the drag force of the sled would primarily be dependent on the frictional forces between the sled and the ground. These drag forces need to be standardised, as they will vary across different test surfaces. For instance, a sled weighing 40 kg dragged on a dirt or concrete surface will have significantly higher drag forces than an identically weighted sled dragged on a wetted grass surface. Standardisation of the drag force in the test would be difficult, as it was unlikely the physiological screening test would be administered on a consistent surface (personal communication, Fire & Rescue NSW). As a result, a second simulated equipment option was considered to simulate the three criterion dragging tasks.

The primary aim of this second option was to minimise, or completely, remove the effect of friction (provided by the difference in surfaces) on these drag forces. Thus, a piece of equipment designed to brake at a range of standardised drag forces was required. This could potentially be fulfilled by the development of a stationary line and reel device (Figure 4.2). This configuration could be engineered to brake at several different drag forces representative of each of the three criterion dragging tasks. A thin, high-tensile, non-stretch line (in blue; Figure 4.2) spooled around the larger drum would be drawn away from the reel by the application of a force. Such forces would be applied through the performance of any of the three criterion dragging tasks. For instance, the performance of the cardiorespiratory drag task would see the cord un-spool from the large drum to a small wheel, set at a height to simulate the direction and height of the drag force of the hose drag task. On the larger drum, different resistance settings (marked 1 or 2; Figure 4.2) could be achieved via the adjustment of a switch to accommodate the differences in drag forces between criterion tasks. Ideally, a fully developed model of this prototype would have numerous resistance settings. Thus, the drag load could be easily varied without the addition of any mass.

There are many advantages of this system. Firstly, since the effect of friction is minimised, the drag force is guaranteed irrespective of test venue. Furthermore, once the drag forces for each task have been quantified, the resistance settings on the reel can be set to precisely replicate each of the three criterion dragging tasks. Finally, the cord can be marked at pre-determined intervals, thus allowing distances to be accurately measured for the physiological screening test without the use of additional assessment equipment. To simulate the muscular actions and direction of force during the performance of the firefighter rescue and dragging the charged 38-mm hose, harnesses and sand-filled hoses respectively could be attached. These attachments would allow for the test to more closely approximate operational conditions and equipment. For instance, rescuing a firefighter requires individuals to lock their arms under the victims armpits or straps of the breathing apparatus and perform a powerful lower-body drag backwards. Therefore, if the force of performing this task was quantified, and a harness was attached to the line and reel resistance loader (Figure 4.2), the muscular actions and physiological attributes required to

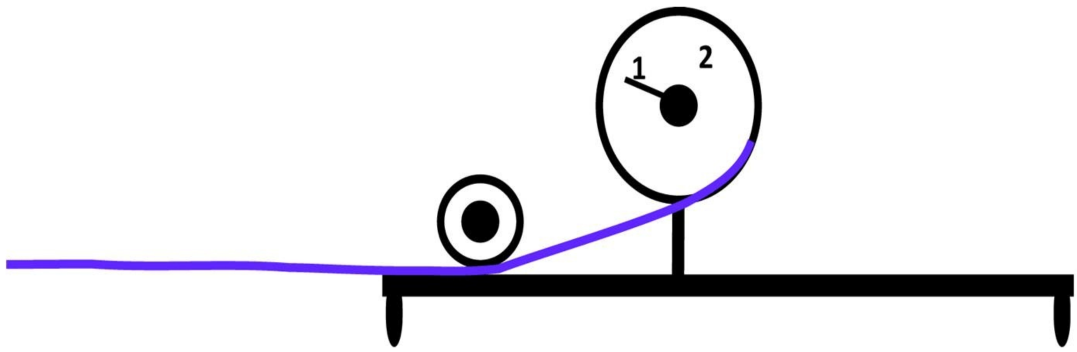

Figure 4.2: Fire simulation line and reel resistance loader for simulated fire attack, firefighter rescue and charged 38-mm cardiorespiratory hose drag tasks. The reel is mounted on a stationary frame. The resistance at which the thin, high-tensile, non-stretch line (illustrated in blue) will be released will be dependant on the frictional loads of the respective simulations. This change in frictional load will occur via the adjustment of a switch (1 or 2).

perform the firefighter rescue could by adequately simulated. This method would also account for the horizontal and vertical forces required to drag the firefighter to safety. Through the aforementioned attachments, the cumulative affect of these two forces can be altered accordingly, to best simulate the resultant drag force of rescuing a fellow firefighter. Moreover, this method would also provide high face validity.

Requirement of a specific mass for the firefighter rescue

For the line and reel resistance loader (Figure 4.2) to be legally defensible for use in the firefighter rescue, the loading must be reflective of a standardised mass chosen by Fire & Rescue NSW. Since this is a rescue of a fellow firefighter, then to this mass must be added the combined mass of the personal protective clothing and equipment worn during structural fire fighting. Two options were considered in the selection of a representative mass to be used within this critical strength task.

The first option was to ascertain the average mass of all operational staff within Fire & Rescue NSW. Indeed, this would reflect the average mass of their fallen colleague a firefighter would be expected to drag. However, Fire & Rescue NSW advised they do not have this information within the organisation's current operational framework, making it difficult to obtain reliable data with sufficient statistical power.

The second option entailed the determination of the mass of an average Australian adult. To calculate the mass in this way also requires the final mass selected to be representative of the fire-fighting workforce, thus avoiding any underlying gender bias. Fire & Rescue NSW advised this gender distribution should encompass one female to every nine males in the operational workforce. Thus, the average mass of the fallen firefighter could be determined using 90% of the average Australian male mass, plus 10% of the average Australian female mass. This method provides an indicative average mass of 82.01 kg (Australian Bureau of Statistics, 2005). The mass of a current Fire & Rescue NSW personal protective ensemble (20kg) would also be added to the chosen mass (82.01 kg). However, there will exist the possibility that firefighters beyond this mass will not be able to be rescued by one person if this average population mass was utilised. For instance, using this mass would mean approximately 50% of rescues will be performed on individuals with a mass that exceeds the average. Since the firefighter rescue is deemed the most critical of all fire-fighting tasks (Chapter Two; Chapter Three), this discrepancy may be unacceptable to Fire & Rescue NSW. Thus, Fire & Rescue NSW may have to implement a threshold at which to set the mass of the critical strength task (*e.g.* 95th percentile).

This average population mass is numerically greater than masses reported in investigations evaluating the demand of operationally simulated firefighter rescues (range: 53-82 kg; Davis *et al.*, 1982; Michaelides *et al.*, 2008). These differences can be attributed to the use of mock victims or dummies in previous studies. In doing so, these investigations did not account for the mass of the personal protective ensemble and breathing apparatus (typically around 20kg) worn by a firefighter during a fire suppression. Indeed, the current physical aptitude test for NSW firefighters involves dragging a 70 kg dummy with no protective gear (personal communication, Fire & Rescue NSW). Since it is unlikely the average mass of an Australian adult was 50 kg at the time of standard development, this mass is an underestimation of what a contemporary firefighter is expected to drag. This evidence supports the inclusion of the simulated firefighter rescue in the proposed physiological screening test. If a recruit is able to successfully perform this task, they will possess the minimum physical and physiological attributes necessary to rescue an individual clothed in the personal protective ensemble.

4.2.2.5 Other operational constraints that could affect all criterion tasks

The conduct of assessments and use of specific fire-fighting equipment within operational Fire & Rescue NSW stations for physiological screening must be carefully considered. For instance, given the detrimental effect of clothing on flexibility, range of motion and maximal exercise (Taylor *et al.*, 2010a), we recommend potential recruits wear the full personal protective ensemble (t-shirt, trousers, overpants, tunic, flash hood, gloves, helmet) when completing the physiological screening test. A full self-contained breathing apparatus should also be worn. The sum of these masses should equate to around 20 kg, however Fire & Rescue NSW will determine this mass. Fire & Rescue NSW indicated (personal communication) boots could not be consistently supplied to recruits for assessment purposes. Thus, recruits will be required to provide their own footwear (sport shoes or joggers) to complete the assessment. Therefore, boots were not included in the total ensemble. However, the metabolic effect of fire-fighting boots has been established (Taylor *et al.*, 2010a), thus we recommend this mass be added to the recruit in the form of a small weighted vest.

Fire & Rescue NSW also stressed the need to consider the lack of absolute control over climatic conditions when administering the screening tests, in particular the temperature. This environmental consideration, while important, is almost impossible to manage consistently and raises many logistical issues. However, significant variations in ambient conditions will influence the ability of firefighters to complete strenuous physical tasks (Sköldström, 1987), thus some standardisation of the ambient conditions in which the physiological screening test is performed in is required. We believe some basic measures could be put in place to minimise the effect of ambient temperature variations on work performance during the assessment. Thus, it is proposed an upper ambient temperature limit be set for the conduct of the assessments. For instance, if ambient temperature exceeded 35°C the physical assessment would not be run.

4.2.3 Proposed physiological screening test for firefighters

For decades, firefighter screening tests have generated much interest for both researchers and fire-fighting organisations. Many investigators have developed firefighter screening tests to include grip strength, anthropometry, muscular strength and cardiorespiratory measurements (Lemon and Hermiston, 1977; Cady *et al.*, 1985; Ellam *et al.*, 1994; Henderson *et al.*, 2007). Comparatively, researchers have developed screening tests involving task-specific components, such as a ladder lift, stair climb and hose drag (Gledhill and Jamnik, 1992b; Rayson *et al.*, 2004). The current investigation proposes a task-specific test comprised of five critical task classes for firefighters (Table 4.2). The proposed physiological screening test includes the most essential, demanding and critical fire-fighting tasks as performed within NSW.

The physiological screening test aimed to possess a high sensitivity, thus inherently providing more reproducible (more reliable) and valid (predictions of job performance) outcomes. This reduced variability between the screening test and the performance of fire-fighting tasks maximises true positives and true negatives and minimises the number of false positive and false negatives. By developing a legally defensible screening test, firefighters who are well suited to cope with the demands of fire-fighting will be identified. This will thereby increase the capability of the fire-fighting workforce, whilst also minimising the risk of injury to employees and members of the wider community. On the basis of the exclusion process undertaken, identification of task constraints and respective modification of remaining tasks in this investigation, we propose a firefighter who can adequately complete each class of activity listed below, will be capable of meeting the physically demanding requirements of contemporary fire fighting as performed within New South Wales, Australia. This assessment comprises five components and these are outlined below;

- Single-sided (unilateral) carriage class task
- Push and holding class task
- Simulated cardiorespiratory hose drag
- Simulated fire attack
- Simulated firefighter rescue

4.2.3.1 Performing the proposed physiological screening test in series

It is recommended the physiological screening test be performed as an uninterrupted sequence of tests (Figure 4.3) that target each of the criterion task classes components identified in section 4.2.3. Further investigation is warranted to determine satisfactory performance (total time to complete the circuit). This will allow individuals of varying physiological capabilities to successfully complete the circuit. Thus, whilst a slow overall performance may not be deemed acceptable, recruits who may be weaker in one test area can compensate by possessing greater abilities on other tasks. This time standard would be dependent upon the minimal acceptable working pace for the tasks that are performed within the circuit, as determined by Fire & Rescue NSW, and as performed by existing operational firefighters. This approach to use a circuit-style format for the performance of multiple critical assessment tasks is well established, and has been validated throughout the

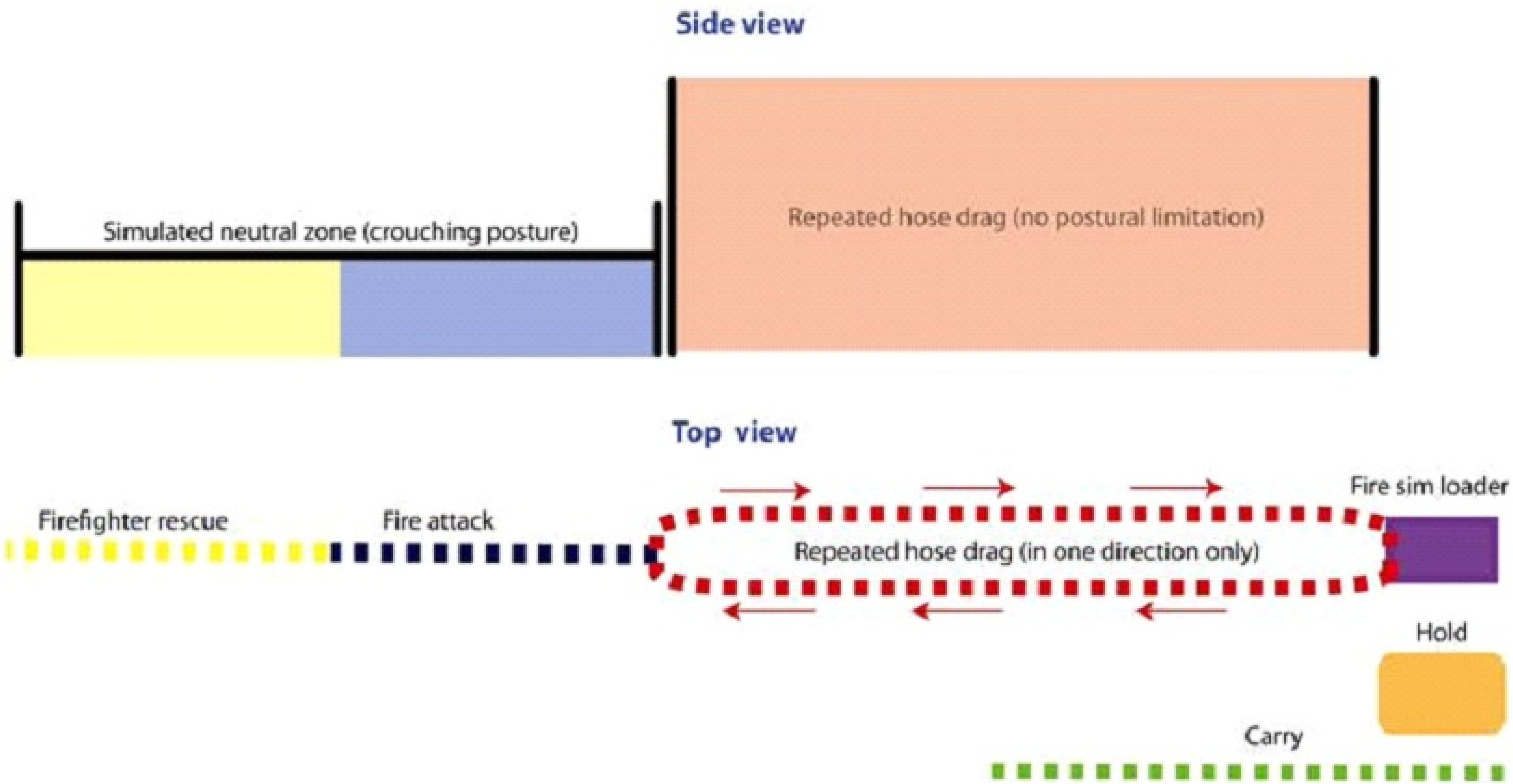

Figure 4.3: The proposed physiological screening test for contemporary firefighters (to be completed in series). The side view illustrates the postural limitation of both the firefighter rescue (yellow) and fire attack (light blue) simulations. The sequence of tasks would be as follows: repeated hose drag (red), fire attack (light blue), firefighter rescue (yellow), holding task (orange and finally a carry task (green).

literature for other emergency service and military occupations (Considine *et al.*, 1976; Brownlie *et al.*, 1985; Taylor *et al.*, 2003 Jamnik *et al.*, 2010a and 2010b).

The logic behind recommending the physiological screening test to be completed in series was to ensure firefighters elicited the peak cardiorespiratory load of fire fighting (1.97 $L.min^{-1}$; Table 3.23). This was important as the task that resulted in this mean value (stair climb with charged 38-mm hose) had been excluded. Furthermore, the physiological screening test to be completed in series was utilised as such to also ensure successful firefighter recruits are capable of resisting fatigue when performing the criterion tasks in succession, an occupational requirement of fire fighting (personal communication, Fire & Rescue NSW). Fatigue is defined as the failure to maintain the required or expected power output (Fitts, 1994), and is present when the physical demands placed on individuals exceed the cardiorespiratory capacity for a given work time (Aminoff *et al.*, 1998). This occurs when indices of high physiological strain, such as oxygen uptake and heart rate, are present (Smolander, 1999; Table 3.23). This is consistent with feedback from focus groups (Chapter Two; Fire & Rescue NSW), who indicated they felt fatigued when performing numerous physically demanding tasks in succession. For example, firefighters will typically perform the location and connection of a hydrant upon arrival at an incident, then immediately commence a fire-attack task.

Nevertheless, to combat fatigue when performing tasks in this circuit-style manner, individuals must possess various physiological attributes such as strength, muscular and whole-body endurance (Gledhill and Jamnik, 1992a and 1992b; Sothmann *et al.*, 2004; Chapter Three). If individuals do not possess these attributes this can lead to potential accidents and problems (Pollock *et al.*, 1998; Wu and Wang, 2001), such as acute myocardial infarction (Mittleman *et al.*, 1993). Individuals who do not have sufficient physiological capacity to meet the most physically demanding and critical tasks of fire fighting will also fail the proposed physiological screening test (Section 4.2.3). Indeed, fatigue of the working musculature and a lower cognitive performance can occur when individuals perform high-intensity intermittent work (Wu and Wang, 2001), a concept prevalent in physically demanding occupations, such as fire fighting (Kivimaki and Lusa, 1994; Bos *et al.*, 2004). Moreover, the prolonged nature of work shifts for firefighters can restrict the amount of rest between incidents, causing cardiorespiratory (Bos *et al.*, 2004) and postural fatigue (Sobeih *et al.*, 2006). The proposed circuit developed in our investigation is consistent with the approach used for physical employment standard development within other occupations (Taylor *et al.*, 2003; Jamnik *et al.* 2010a and 2010b).

Indeed, the prevalence of loaded cardiorespiratory endurance activities within the proposed physiological screening test (Section 4.2.3; Table 3.40) warrants the performance of the proposed physiological screening test as a circuit (Figure 4.2). Thus, overall task performance (time taken to complete the circuit) will reflect cardiorespiratory endurance of the potential recruits. This is consistent with findings for Navy clearance divers (Taylor *et al.*, 2003), those proceeding the establishment of various physiological competencies (*e.g.* cardiorespiratory requirements) of this trade (Taylor *et al.*, 2000). Since fire fighting is associated with fatigue under typical operational scenarios, we argue the proposed fitness battery completed in series will lend support to the valid identification of capable recruits. Such individuals will be able to combat the onset of fatigue, as they possess the physiological attributes necessary to complete the tasks in a operationally safe and efficient manner (Gledhill and Jamnik, 1992b). Notwithstanding this, it must be noted that ultimately the legal defensibility and ecological validity of the proposed physiological screening test is due to the operational sequence and relevance of the simulated trade tasks.

4.3 FUTURE RECOMMENDATIONS

In this investigation a wide range of physical tests were established that, in combination, are believed to represent a legally defensible physiological screening test for firefighters. Given the operational and equipment changes since the work done from which the current entry-level screening tests for NSW recruit firefighters were based (Gledhill and Jamnik, 1992a and 1992; Fire & Rescue News, 2011), the development of a test that replicated the full demands of the occupation (Bilzon *et al.*, 2001b, Garver *et al.*, 2005) was necessary. This was conducted through an exclusion process and the analysis of operational constraints for remaining criterion tasks. Thus, an evaluation of these processes and constraints was the logic behind this investigation. By ascertaining information regarding these evaluations, further investigation to determine the effect of substituting criterion tasks within the proposed physiological screening test which share similar physiological and movement attributes can be conducted. Therefore, recommendations were also put forward to explore possible existing inter-relationships between criterion tasks and relevant basic physical tests. If these basic physical tests possess criterion validity (Equal Employment Opportunity, 1978), they can be used to predict fire-fighting performance. Furthermore, this will assist to alleviate possible limitations (Figure 4.1b) of administering the screening test across the State, as administering basic physical tests are efficient, inexpensive and do not involve a high degree of skill.

4.3.1 Alternative tasks to predict performance in physically demanding occupations

When it is impractical to take precise measurements to classify an individual's ability in the workplace, predictive tools of performance can be used. For example, it might be impractical and expensive for Fire & Rescue NSW to distribute spreaders (mass: 19.5kg) around the State for the motor-vehicle rescue task. In the current project, variables were identified that might potentially predict the functional performance of firefighters. Thus, this research focussed on developing screening items with an increased sensitivity, items that possess the potential to correctly identify capable firefighters. If these predictive screening items have a high sensitivity, they become more reliable, valid (providing predictions of job performance) and thus, more legally defensible (Taylor and Groeller, 2003; Gumieniak *et al.*, 2011).

For instance, we recommend the assessment of a simple lifting task (box lift and place) to predict the performance on more complex fire-fighting activities (motor-vehicle rescue) be further investigated. There is evidence in the literature to suggest strong correlations exist with manual-handling task performance and strength measures, especially with progressions in resistance training (Sharp *et al.*, 1993a; Kraemer *et al.*, 2001). Indeed, isometric strength measures and lean body mass are adequate in deriving predictive equations for maximal lifting capacity of male and female army personnel (Teves *et al.*, 1985). This is consistent with the known strong associations between lift performance and upright-pull strength measures (Sharp *et al.,* 1980). Furthermore, effective models using physical scores have been developed to predict the performance of maximal and repetitive box lift and carry (Kraemer *et al.*, 1998). Moreover, Knapnik *et al.* (1999) produced equations comprising push ups and lean body cross-sectional area (thigh and forearm) that strongly predicted (r=0.99) stretcher carry duration. We believe this evidence provides support towards the recommended investigation of the ability of alternate strength tasks, such as the box lift and place, to predict fire-fighting performance of holding tasks included in the proposed physiological screening test.

Previous authors have also evaluated the ability of other strength tasks to predict performance in physically demanding occupations (Davis *et al.*, 1982; Henderson *et al.*, 2007; Michaelides *et al.,* 2008). For instance, the positive correlations between grip strength and endurance with manual handling tasks, such as one-handed load carriage, have been established (Rice and Sharp, 1994). This suggests grip strength could potentially predict the performance of the single-sided load carriage tasks utilised in our investigation. However, at face value a grip strength test does not appear to be representative of a typical fire-fighting task. This lack of face validity when developing screening tests for physically demanding occupations has appeared in previous work. For example, in a study designed to develop physical employment standards for the British Army, Rayson *et al.*, (2000) evaluated the performance of 379 trained soldiers on basic physical tests and a test battery, deriving various models to predict load carriage time of a 3.2km march, with the most statistically significant model (r=0.88), entailing various body composition and back extension strength measures. As part of their overall project, these authors also derived statistically significant predictive models for lifting and carriage performance. However, there were large errors for some of the criterion tasks that predicted performance of a range of military tasks in these studies. Therefore, these models are not appropriate for use as they entail large errors and do not ascertain adequate face validity. Our investigation focussed on producing valid screening items which reflected the most physically demanding fire-fighting tasks (Constable and Palmer, 2000; Gledhill and Bonneau, 2001), to ensure these standards were legally defensible (Gumieniak *et al.,* 2011).

More recently, Milligan *et al* (2010) evaluated 84 subjects performing the Tecumseh step test and a six minute walk test to assess whether the walk test offered a valid alternative for the indirect assessment of occupational aerobic fitness. Heart rate responses for the Tecumseh test demonstrated a significant correlation (r=0.81) with the six minute walk test. Furthermore, stair-climbing ability and six minute walk time (flat ground) have been demonstrated to possess similar accuracy and sensitivity (Cateneo *et al.*, 2010). Moreover, significant correlations have been established between maximal oxygen consumption and stair-climbing speed during cycle ergometry (Koegelenberg *et al.*, 2008). Since the access to stairs for the administering of screening tests around the state is unlikely, these studies have significant implications for future research within this field. However, they do not account for loaded stair carriage, and this is a concern given all tasks involving stairs in this project involved some considerable form of load carriage (Appendix Three). Load carriage ability can be determined by a number factors, including aerobic power, muscular strength, placement of the load and anthropometric dimensions (Haisman, 1988). Predictive correlations between the relative performance of loaded stair-climbing tasks and tasks conducted on flat terrain need to be established for a possible screening test to be both valid and legally defensible. The evaluation of tests to alleviate these issues warrants further investigation, and it is recommended Fire & Rescue NSW pursue such evaluations.

An example of a loaded stair-climb investigation for physically demanding occupations in the recent literature was the development of fitness standards for the UK Oil and Gas Industry (Milligan *et al.*, 2010). These investigators evaluated the physiological responses of individuals performing a unilateral load carriage (20 kg) up a flight of 15 steps for three minutes, reporting a mean relative oxygen consumption of 33.4 $mL.kg^{-1}.min^{-1}$. Unfortunately there was no comparable data on flat terrain for the work of Milligan *et al.* (2010). However, some of these authors have previously shown step tests can be validly replaced by walking tests on flat terrain for the indirect sub-maximal assessment of aerobic fitness (Reilly and Tipton, 2010). Given these data, it is not unreasonable to hypothesize that a loaded flat-terrain task could predict a loaded stair-climb task. Evaluating such a prediction will permit the comparison of the relative physical demands of the stair climb with a ventilation fan with other carriage tasks that are conducted on flat terrain (*e.g.*

hazmat task; Section 4.4).

Ratings of perceived exertion suggest stair-climbing tasks are more demanding, or at least perceived to be, than flat-terrain tasks (Table 3.40). Furthermore, the highest recorded mean oxygen consumption in Chapter Three was the stair climb with charged 38-mm hose (1.97 $L.min^{-1}$; Table 3.23). Because of the vertical component, loaded stair climbing requires a highly specific physical strength, suggesting carrying a load up stairs is best represented by a direct task simulation, rather than an indirect predictor of performance (Reilly and Tipton, 2010). However, the lack of access to stairs for the administering of screening tests around the State warrants the investigation of suitable alternatives.

To investigate alternative approaches to the simulation or duplication of critical fire-fighting tasks, we recommend the evaluation of physiological performance across a range of simulated trade-tasks and basic physical tests. Such an investigation will allow for relationships amongst these tasks to be explored. If these basic skills tests are shown to be strong predictors of simulated trade-task performance, the final recommended physiological screening test could include more basic tests to suit test administration, as determined from the analyses of the task items outlined below. The following points outline the recommended procedures from which we believe would provide the most support for the development of valid and time-efficient tests for selecting capable fire-fighting recruits. These tasks are recommended to be performed separately, then each in series without rest to represent a typical operational fire-fighting scenario. It is recommended potential recruits are familiarised with the equipment used throughout the test (including the personal protective ensemble). This exposure would reduce possible inefficiencies caused by such equipment. The analysis of the data derived from these tasks is beyond the realms of this dissertation.

4.3.1.1 Single-sided unilateral carriage task items

Task A - Hazmat incident replication

It is recommended subjects perform a replication of the hazmat incident at a self-selected pace. Subjects will be instructed to keep an upright posture, one foot on the ground at all times and complete the task as quickly and safely (no running) as possible. Subjects will unilaterally carry a 26 kg-mass (water filled jerry can) for 64 m and perform this routine eight times (eight laps; total distance 512 m). Subjects are free to stop at any time and may change hand as required. Performance will be assessed from the time to complete the circuit.

Task B - Hazmat incident replication (three speeds)

Subjects will perform the hazmat task, but now at three different walking speeds. Subjects will carry the 26 kg mass continuously for 5 min three times each at a different speed: slow, medium and fast. These speeds will be dictated by the researcher, but will be subject specific from each subjects performance in task A. Performance will be assessed by the examination of metabolic cost.

Task C - Loaded stair climb

It is recommended subjects perform a replication of the ventilation fan carry. Thus, this task will commence on flat ground and involve the unilateral carriage of a 17.5 kg mass for 7.3 m before ascending 64 stairs (4 storeys). Subjects will be instructed to perform this task as quickly yet as safely as possible (no running) with an upright posture. Subjects are free to stop at any time and may change hand as required. Performance will be assessed from the time to complete the task.

Task D - Loaded box step (three speeds)

It is recommended subjects perform a loaded box-stepping task. Rather than completing the task C, subjects will carry the 17.5 kg mass continuously while stepping onto, and off, a 26-cm high box step for 5 min three times each at a different speed: slow, medium and fast. Subjects will be instructed to perform this task as quickly yet as safely as possible (no running) with an upright posture. These speeds will be dictated by the researcher, but will be subject specific from each subjects performance in task C. Performance will be assessed by the examination of metabolic cost. Subjects are free to stop at any time and may change hands as required.

4.3.1.2 Holding tasks

We recommend that an investigation of single- and repetitive-lift and place performance, or alternatively a generic holding task, be assessed with the simulated criterion tasks which require a holding demand. However, to effectively complete this research, advice from the subject-matter experts within Fire & Rescue NSW is required. Fire & Rescue NSW must advise whether these holding tasks are performed operationally at an absolute or relative height. It is critical the final selection of a height (or heights), whether absolute or relative, be determined solely on the basis of Fire & Rescue NSW's operational demands and procedures. For instance, task demands may change significantly between individuals of different stature when performing a task at an absolute height. If a relative height is adopted, then we need to know this in the form of a percentage of each participant's standing height, as determined by Fire & Rescue NSW.

Task E - Motor-vehicle rescue replication

It is recommended subjects perform a replication of the motor-vehicle rescue. Subjects will perform a series of static holds with a replicated spreaders tool (19.5 kg) for six min. This activity will involve six different positions for the tool to be held, each lasting one min. These positions will be relative to the subject: knee height (left and right sides, hip height (left and right sides), and head height (left and right sides). The order of these during the trial will be randomised. Within each minute (one min at each position) subjects will perform a hold, then rest the object onto a bench of the same height. This is to replicate when the spreaders are locked onto the motor vehicle and thus, take the majority of the load held. Three trials will encompass different ratios of the duration of these hold and rest periods within each minute. This will be controlled by the researcher: 20-s hold (40-s rest), 30-s hold (30-s rest), and 40-s hold (20-s rest). A fourth trial will involve the subject performing a static hold to failure in each of the six positions. Termination criteria will include the inability to hold the mass at the set height or not maintaining a safe and correct posture. Performance will be assessed by the examination of metabolic cost. Subjects are free to stop at any time.

Task F- Maximal box lift and place

Subjects will lift a box from the ground and place it on a platform 1.5 m above the ground. The box should be cubical in shape and the weight evenly distributed. The aim of this task is to determine the maximal load a person can lift to the set height while maintaining a correct lifting posture (neutral spine, no stooping or excessive lordosis, bent knees, no jerking), in a controlled and safe manner. The failure to abide by these criteria will result in test failure. Subjects will commence lifting with masses of 10 kg for women and 20 kg for men. If the lift is successful, the subject will rest for 3 min whilst additional weight is added to the box. This cycle will continue until the subject can no longer safely lift the box to the desired height.

Task G - Endurance box lift and place

Subjects will perform a box lift and place as per above. However, rather than performing a maximal lift, the subjects will also return a lighter box (19.5 kg) to the ground, and then with no rest, perform the lift again. This cycle will be repeated until the subject is unable to continue to place the box on the shelf. This activity aims to determine how many times a subject can safely lift a box consecutively with no rest. The additional termination criteria are as per above for the maximal box lift and place.

Task H - Ladder-raise simulation (One repetition maximum; Smith machine shoulder press)

It is recommended subjects perform a replication of the ladder raise by performing a one repetition maximum of a seated shoulder press (Smith machine). The safe protocol for raising the mass should be taught to the subjects prior to the performance of the task but will mirror the actions performed when performing a ladder raise. The aim of this task is to determine the maximal load a person can shoulder press while maintaining a correct lifting posture (neutral spine, no stooping or excessive lordosis, bent knees, no jerking), in a controlled and safe manner. The failure to abide by these criteria will result in test failure. Subjects will commence pressing with masses of 15 kg for women and 30 kg for men. If the press is successful, the subject will rest for 2 min whilst additional weight is added to the bar. This cycle will continue until the subject can no longer raise the mass.

Task I - Ladder-raise task

Subjects will perform an individual ladder (10.5 m; 49.6 kg) raise from the ground (where one of the ladder ends will be anchored) to a vertical wall. This procedure should be taught by personnel from Fire & Rescue NSW, and performed accordingly. One hand must be in contact with the rungs of the ladder at all times. One foot on the ground at all times must also be enforced. This task will be performed as quickly, yet as safely as possible. Performance will be assessed by the time to complete the task. Incorrect technique will result in the termination of the test (lack of neutral spine, stooped posture, excessive lordosis, jerky movements). Safety lines should be attached to the ladder to ensure, that if the subjects loses control of the ladder, they can release the ladder without risk of injury. However, this tension will not assist the raising of the ladder.

4.3.1.3 Hose-dragging tasks

Task J- Hose-drag replication

It is recommended subjects perform a replication of the 38-mm charged hose drag. It is recommended that the restrictive load of this task be determined and simulated using the reel and line resistance device. Subjects should drag the line intermittently (20 m) before returning (unloaded) to the reel and performing the tasks again. This sequence is repeated over a 50 min duration. Performance will be assessed from a measurement of the total distance covered in the time period. This task will be performed as quickly, yet as safely as possible. Subjects must keep a safe, upright posture and can stop at any time.

Task K - Hose-drag replication (three speeds)

Subjects will perform the above task but this time at three speeds: slow, medium and fast. The fastest speed will be set by the subjects performance in Task J, as monitored and controlled by the researcher. The medium and slow speeds will be relative to the average speed of Task J. As per above, the distance that the hose is to be dragged will be limited to 20 m, upon which the subject will return (unloaded) to the reel and resistance loader, from which they will commence the next-hose drag simulation. This task will be performed until 15 min has elapsed for each speed (three trials). The MetaMax 3B will measure metabolic cost of the activity and subjects will be instructed to maintain a safe and upright posture.

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APPENDIX ONE:

INVITATION TO PARTICIPATE IN AN ONLINE SURVEY:

TOPIC: PHYSICALLY DEMANDING DUTIES WITHIN FIRE AND RESCUE NSW

Participant information:

This research project is being undertaken by the Centre for Human and Applied Physiology at the University of Wollongong, and it is funded by Fire and Rescue NSW. Many firefighters will already be aware of this research, the broad aims of which are to develop age- and gender-neutral physical employment standards (tests of work-related physical fitness) for permanent and retained firefighters in NSW. The Fire Brigade Employee Union has already been briefed on the aims of this project. The completion of this task during work time has been approved by Fire and Rescue NSW.

There are several research phases for this project, and these are necessary to ensure that such employment standards are both a fair and reasonable reflection of the physical fitness required to be a firefighter, whilst not being discriminatory in nature. The first phase of this research was conducted through a series of interviews and round-table discussions with 106 firefighters (across all ranks) from eleven metropolitan and regional Fire Stations. Interviews involved 69 permanent and 38 retained firefighters, including 12 female firefighters, and 45 participants with 15 or more years of experience as operational firefighters. These interviews resulted in identifying a comprehensive list of the physically demanding tasks of fire fighting, and that list now forms the basis of this survey.

The aim of the survey is to obtain the opinions of all firefighters across NSW. In so doing, the research team will not only be able to validate the current list of physically demanding tasks, but it will now have considerable confidence in ranking these tasks according to their importance, physical effort and the frequency of their performance, since you and your peers (permanent and retained firefighters), through this survey, will determine this outcome. That is, the researchers will use your responses to determine the average importance, physical effort and performance frequency of these tasks at metropolitan, regional and retained Fire Stations.

Other important information:

This survey will take approximately 15 minutes to complete. Before you decide on participating, please take note of the following important points:

- **Voluntary Participation:** Your participation in this project is entirely voluntary. You are free to deny consent at any stage during the survey, and you do this activating the WITHDRAW button at the bottom of the survey.
- **Informed Consent:** In completing this survey, you are confirming that you have read and understood the information contained within this note and that you are voluntarily participating. If you do not wish to participate in the survey, then please do not answer any of the questions. You can, of course, read the information and questions without participating, and you can use the WITHDRAW button at any time.
- **Confidentiality:** All information that you provide will be treated in complete confidence and privacy. You will be given a unique participant code (please record this for your future reference). The researchers will use that code, but no one, other than yourself, will know your identity. Therefore, the resulting data will be stored separately from any information that could identify you. Fire and Rescue NSW will not be permitted access to any data that could be used to identify individual participants.
- **Data use:** Aggregate results, but not individual responses will be used from this survey. These data will be used for research purposes. Overall responses will be reported to Fire and Rescue NSW in the form of a technical report, and these may also be subsequently reported within scientific and academic journals.
- **Funding:** This research project has been funded by Fire and Rescue NSW.
- **Ethical considerations:** The researchers adhere to the principles governing both the ethical conduct of research and the protection (at all times) of the

interests, comfort and safety of participants. All research activities associated with the physical employment standards project for Fire and Rescue NSW, including this survey, have been approved by the Human Research Ethics Committee (University of Wollongong).

Inquiries:

Questions concerning the procedures, or rationale used in this investigation are welcome at any time. Please ask for clarification of any point that you feel is not explained to your satisfaction. Your initial contact person is Assoc. Prof. Nigel Taylor (School of Health Sciences, University of Wollongong: phone 02-4221-3463), the chief investigator for the project. You may also direct electronic mail to Nigel through Hugh Fullagar (hhkf238@uow.edu.au). For further information about the conduct of human experiments, please contact the Secretary of the Human Research Ethics Committee, University of Wollongong (phone: 02-4221-4457).

For most questions respondents either selected one answer from several options that were provided, or simply entered numbers or text to answer each question. The online survey allowed participants to save their answers at each screen if they wished to complete the survey in separate steps using the NEXT and SAVE button and they could also return to previous questions to change their answers using the PREV button. If the survey unexpectedly closed or the participant wished to complete the survey at a later date, the link used would return to the last page where upon the participant pressed the NEXT and SAVE button.

ONLINE SURVEY OF PHYSICALLY DEMANDING FIREFIGHTER DUTIES:

FIREFIGHTERS OF FIRE AND RESCUE NSW

SCREEN ONE:

Thank you for participating in this survey. We ask that you please complete all sections, and this should take approximately 15 minutes. For most questions, you can use the mouse to put the cursor over the relevant box, and use the left button to click on that box. This will place a marker in the chosen box. If you change your mind, you can simply click on another box, and the marker will automatically move to the new location. For a few questions, we are wanting you to enter numbers or text. Please put this information in the boxes indicated.

At the bottom of the survey there are two buttons that can be activated with the mouse. Click the WITHDRAW FROM SURVEY to cease taking part in the survey. To complete the survey, and also to request that your information is sent to the research team for inclusion within this evaluation process, you MUST click the I VOLUNTEER TO COMPLETE THIS SURVEY. Remember, you must click SUBMIT to request that your responses are sent to the researchers.

In activating the I VOLUNTEER box below, I signify that I have read the survey participant information for this activity, and that I am voluntarily participating in the survey. I also understand that I cannot be identified, and that I will be given a unique participant code. The researchers will use that code, but no one other than myself will know my identity. I also grant permission for the researchers to use my answers to compile aggregate responses to these questions, and to report these results to Fire and Rescue NSW and in various publications.

(1) Your participation in this survey is entirely voluntary. If you do not wish to proceed with this survey select WITHDRAW FROM SURVEY; or if you wish to participate in the survey select I VOLUNTEER TO COMPLETE THIS SURVEY

SCREEN TWO

(2) Are you a permanent or retained firefighter? Choose from scroll down bar:

Permanent, retained, other.

SCREEN THREE

(3) What is your rank? Choose from scroll down bar:

Firefighter, qualified firefighter, senior firefighter, leading firefighter, station officer, inspector, super-intendant, chief super-intendant, other senior/executive officer.

SCREEN FOUR

(4) How long have you been an employee of Fire and Rescue NSW (previously NSWFB)?

Enter data in years (whole numbers only please).

(5) What is your current age in years?

Enter data in years (whole numbers only please).

(6) Are you male or female? Choose from scroll down bar:

Male or female.

(7) Please indicate if you are currently a Permanent or Retained firefighter, based in the metropolitan or regional area. Choose from scroll down bar:

Metropolitan (permanent), metropolitan (retained), regional (permanent), regional (retained), operational support.

(8) How many years have you worked in each of the following classifications? :

Metropolitan (permanent), metropolitan (retained), regional (permanent), regional (retained), operational support. Round up or down to the nearest whole year. If less than one year enter 1.

SCREEN FIVE

Please answer the following questions regarding your experiences as a firefighter. We are trying to learn more about your job, and the difficulty of certain tasks that you have performed as part of that job. On this page you will be given a number of firefighting tasks to review. For each of these tasks we will ask you to rate them in 4 different ways using a drop down scale.

i) IMPORTANCE

We recognise that almost every fire fighting task is very important, but we want you to consider importance only relative to the urgency associated with saving life and property. A 1 to 5 point rating will be used.

ii) PHYSICAL EFFORT

On average, how much physical effort is required to perform the task. A 1 to 5 point rating will be used.

iii) TIMES PER YEAR

What is the average number of times you perform this task per year?

iv) AVERAGE DURATION OF TASK

In your experience, what is the average duration for which the task is performed?

(9) Rate the following tasks for importance, physical effort, times per year and time spent on the task during a callout.

- Bowling out 70 mm hose
- Bowling out 38 mm hose
- Locating hydrant, carrying equipment and getting water to appliance
- Coupling/uncoupling hoses
- Dragging 70 mm charged hose across a horizontal surface
- Dragging 38 mm charged hose across a horizontal surface
- Dragging 38 mm charged hose up a stairway
- Stair climbing with PPE, BA and charged hose
- Stair climbing with PPE, BA, high rise pack, axe and halligan tool
- Prolonged use of charged hose: 38 mm (1 person)

- Prolonged use of charged hose: 70 mm (2 people)
- Prolonged crawling, kneeling, crouching, squatting: fire attack
- 4.6. m “Jumbo/Little Giant” ladder use: gaining access and/or rescue/salvage work
- 10.5 m ladder use: under running, stabilisation
- 10.5 m ladder use: 2 person removal and replacement
- Rescue via ladder (2 person)
- Rescue victim via stairs (2 person)
- Rescue firefighter while wearing PPE and BA (1 person)
- Rescue victim while wearing PPE and BA (2 person)
- Moving victims with salvage sheets or Stokes litter
- Using spreaders and shears
- Prolonged static work (e.g. holding victim's head)
- Using sledge hammer to gain entry
- Carrying ventilation fan up stairs (2 person)
- Carrying Davey pump (2 person)
- Pulling down ceiling using ceiling hook
- Hazmat: prolonged walking and manual handling in fully encapsulated suit
- Tunnel search and rescue
- Bush: prolonged walking with cordage pack or Stokes Litter
- Bush: dragging charged hose on hilly, sloped, uneven surfaces
- Bush: digging fire break (McLeod Tool)
- Any other task (please list and rate)

SCREEN SIX

Please answer the following questions regarding the physical capacity you believe is required to be a firefighter.

(10) Have you ever found that your ability to perform one of the tasks listed below was limited by some aspect of your physical capacity (e.g. strength, endurance or

cardiovascular fitness) ? Please select YES or NO for each task.

- Bowling out 70 mm hose
- Bowling out 38 mm hose
- Locating hydrant, carrying equipment and getting water to appliance
- Coupling/uncoupling hoses
- Dragging 70 mm charged hose across a horizontal surface
- Dragging 38 mm charged hose across a horizontal surface
- Dragging 38 mm charged hose up a stairway
- Stair climbing with PPE, BA and charged hose
- Stair climbing with PPE, BA, high rise pack, axe and halligan tool
- Prolonged use of charged hose: 38 mm (1 person)
- Prolonged use of charged hose: 70 mm (2 person)
- Prolonged crawling, kneeling, crouching, squatting: fire attack
- 4.6. m “Jumbo/Little Giant” ladder use: gaining access and/or rescue/salvage work
- 10.5 m ladder use: under running, stabilisation
- 10.5 m ladder use: 2 person removal and replacement
- Rescue via ladder (2 person)
- Rescue victim via stairs (2 person)
- Rescue firefighter while wearing PPE and BA (1 person)
- Rescue victim while wearing PPE and BA (2 person)
- Moving victims with salvage sheets or Stokes litter
- Using spreaders and shears
- Prolonged static work (e.g. holding victim's head)
- Using sledge hammer to gain entry
- Carrying ventilation fan up stairs (2 person)

- Carrying Davey pump (2 person)
- Pulling down ceiling using ceiling hook
- Hazmat: prolonged walking and manual handling in fully encapsulated suit
- Tunnel search and rescue
- Bush: prolonged walking with cordage pack or Stokes Litter
- Bush: dragging charged hose on hilly, sloped, uneven surfaces
- Bush: digging fire break (McLeod Tool)
- Any other task (please list and rate)

SCREEN SEVEN

(11) If you feel that we have failed to include some tasks that you consider to be as physically demanding, or even more demanding, then please send an electronic mail message to Hugh Fullagar (hhkf238@uowmail.edu.au). In that message, please name and briefly describe each task that you would like to add to this list. Alternatively, if you would like to make any comments concerning the survey or any other aspect of this research, you may enter these comments in the box below (there is a space limitation of 1,000 characters (including spaces)). Like all other parts of this survey, these comments will be kept confidential.

SCREEN EIGHT

13) The survey is now finished. Please press SUBMIT. Thank you for taking part in the survey, your time is much appreciated.

APPENDIX TWO

Tasks grouped into categories as defined by the training needs analysis (Endeavour Training and Development, 2010):

Code 28: Gain access to incident

- Using power saw (cutter) use to gain entry
- Carrying rapid intervention kit (RIK) to gain entry
- Ladder use: removal, replacement, under running
- Ladder stabilisation: usually 2-3 people, sometimes 1 person
- Using sledge hammer to gain entry
- Pulling down ceiling using ceiling hook
- Lifting, positioning and stabilising spreaders
- Lifting, positioning and stabilising shears
- Using crowbar (2-metre bar) to lever open vehicle doors/bonnet
- Removal of vehicle doors and rooves following accident
- Breaking through or jumping over fences
- Lifting and carrying heavy objects
- Other tool use (see code 111)

Code 37: Remove people, victims, deceased from scene

- Moving people (often obese) using canvas/salvage sheets
- Rescue firefighter/victim while wearing PPE and BA
- Rescue via ladder
- Rescue via stairs
- Prolonged crawling, kneeling, crouching, squatting, dragging: rescue
- Ladder use: removal, replacement, under running
- Ladder stabilisation: usually 2-3 people, sometimes 1 person
- Prolonged static work (*e.g.* holding victim's head)
- Moving victims with Stokes Litter (cliff rescue)

Code 49: Assist with primary search

- Using power saw (cutter) use to gain entry

- Carrying rapid intervention kit (RIK) for gaining entry
- Dragging and holding charged hose
- Stair climbing with PPE, BA and charged hose
- Stair climbing with PPE, BA, charged hose, high rise fire fighting, axe and halligan tool
- Prolonged crawling, kneeling, crouching, squatting: search
- Moving slabs of concrete following building collapse
- Lifting and carrying heavy objects
- Removal of vehicle doors and rooves following accident
- Carrying charged line of hose onto and throughout a ship

Code 50: Contain and extinguish fire

- Rolling out uncharged hose lines
- Finding hydrant and carrying the necessary equipment
- "Draughting" with suction hose attachments to obtain water
- Stair climbing with PPE, BA and charged hose
- Stair climbing with PPE, BA, charged hose, high rise fire fighting, axe and halligan tool
- Coupling and uncoupling hoses
- Dragging charged hose through buildings
- Prolonged holding of charged hose: 38 mm
- Prolonged holding of charged hose: 70 mm
- Prolonged crawling, kneeling, crouching, squatting: fire search
- Prolonged crawling, kneeling, crouching, squatting: fire attack
- Carrying charged line of hose onto and throughout a ship
- Bush: prolonged walking in bushland carrying cordage pack
- Bush: dragging charged hose (3-4 lengths; 25 mm or 38 mm) for 100 metres on hilly, sloped, uneven surfaces
- Bush: digging fire break using McLeod Tool (hoe)

Code 52: Operate pump and related equipment at incident

- Rolling out uncharged hose lines
- Finding hydrant and carrying the necessary equipment
- "Draughting" with suction hose attachments to obtain water
- Coupling and uncoupling hoses
- Carry generator, usually 10-20 metres but can be up to 100 metres, strength based
- Carrying block sets and tools to stabilise vehicle
- Lifting, positioning and stabilising spreaders
- Lifting, positioning and stabilising shears
- Using air-operated (hydraulic) tools
- Carrying hydraulic pump or Davey pump (two-person lifts)
- Carrying power generator (two-person lift)
- Hydraulic hose unwind and rewind
- Carrying ventilation fan up stairs (two-person lift)

Code 53: Use hoses correctly

- Rolling out uncharged hose lines
- Finding hydrant and carrying the necessary equipment
- "Draughting" with suction hose attachments to obtain water
- Coupling and uncoupling hoses
- Dragging charged hose through buildings
- Stair climbing with PPE, BA and charged hose
- Stair climbing with PPE, BA, charged hose, high rise fire fighting, axe and halligan tool
- Dragging charged line of hose onto and throughout a ship
- Prolonged holding of charged hose: 38 mm
- Prolonged holding of charged hose: 70 mm
- Hydraulic hose unwind and rewind
- Bush: dragging charged hose (3-4 lengths; 25 mm or 38 mm) for 100 metres on hilly, sloped, uneven surfaces

- Rolling lines of uncharged 38 mm and 70 mm hose
- Under running wet hoses and hoisting hoses up the whips
- Flaking hose trays and loading onto appliance

Code 55: Assist with tactical ventilation

- Carrying ventilation fan up stairs (two-person lift) often in confined spaces and with awkward postures: climbing stairs, steep slopes, on-board ship

Code 59: Retrieve people, injured, deceased from scene

- Moving people (often obese) using canvas/salvage sheets
- Rescue firefighter/victim while wearing PPE and BA
- Rescue via ladder
- Rescue via stairs
- Prolonged crawling, kneeling, crouching, squatting, dragging: rescue
- Ladder use: removal, replacement, under running
- Ladder stabilisation: usually 2-3 people, sometimes 1 person
- Prolonged static work (*e.g.* holding victim's head)
- Moving victims with Stokes Litter (cliff rescue)

Code 60: Use stokes litter to rescue victim

- Moving victims with Stokes Litter (cliff rescue)
- Rescue via ladder with Stokes Litter
- Bush: prolonged Stokes Litter carry: 1 km on rough terrain

Code 61: Work on roof

- Ladder use: removal, replacement, under running
- Ladder stabilisation: usually 2-3 people, sometimes 1 person
- Rescue via ladder: two-person
- Rescue via ladder with Stokes Litter
- Salvage and overhaul: external

Code 65: Use hoses in a fuel fire

- Rolling out uncharged hose lines
- Finding hydrant and carrying the necessary equipment
- "Draughting" with suction hose attachments to obtain water
- Coupling and uncoupling hoses
- Dragging charged hose through buildings
- Stair climbing with PPE, BA and charged hose
- Stair climbing with PPE, BA, charged hose, high rise fire fighting, axe and halligan tool
- Dragging charged line of hose onto and throughout a ship
- Prolonged holding of charged hose: 38 mm
- Prolonged holding of charged hose: 70 mm
- Hydraulic hose unwind and rewind
- Bush: dragging charged hose (3-4 lengths; 25 mm or 38 mm) for 100 metres on hilly, sloped, uneven surfaces
- Rolling lines of uncharged 38 mm and 70 mm hose
- Under running wet hoses and hoisting hoses up the whips
- Flaking hose trays and loading onto appliance

Code 68: Rescue, extricate victims

- Moving victims with Stokes Litter (cliff rescue)
- Lifting, positioning and stabilising spreaders
- Lifting, positioning and stabilising shears
- Using crowbar (2-metre bar) to lever open vehicle doors/bonnet
- Removal of vehicle doors and rooves following accident
- Prolonged static work (*e.g.* holding victim's head)

Code 78: Operate portable pump and related equipment

- Carrying Davey pump (two-person lifts)
- Coupling and uncoupling hoses

Code 79: Operate vehicle mounted pump and related equipment

- "Draughting" with suction hose attachments to obtain water or to drain flood area

Code 80: Use hoses correctly

- Rolling out uncharged hose lines
- Finding hydrant and carrying the necessary equipment
- "Draughting" with suction hose attachments to obtain water
- Coupling and uncoupling hoses
- Dragging charged hose through buildings
- Stair climbing with PPE, BA and charged hose
- Stair climbing with PPE, BA, charged hose, high rise fire fighting, axe and halligan tool
- Dragging charged line of hose onto and throughout a ship
- Prolonged holding of charged hose: 38 mm
- Prolonged holding of charged hose: 70 mm
- Hydraulic hose unwind and rewind
- Bush: dragging charged hose (3-4 lengths; 25 mm or 38 mm) for 100 metres on hilly, sloped, uneven surfaces
- Rolling lines of uncharged 38 mm and 70 mm hose
- Under running wet hoses and hoisting hoses up the whips
- Flaking hose trays and loading onto appliance

Code 110: Assist with vertical extrication

- Rescue via ladder
- Rescue via stairs
- Ladder use: removal, replacement, under running
- Ladder stabilisation: usually 2-3 people, sometimes 1 person
- Moving victims with Stokes Litter (cliff rescue)

Code 111: Operate rescue equipment

- Moving victims with Stokes Litter (cliff rescue)
- Rescue via ladder with Stokes Litter
- Ladder use: removal, replacement, under running
- Ladder stabilisation: usually 2-3 people, sometimes 1 person
- Lifting, positioning and stabilising spreaders
- Lifting, positioning and stabilising shears
- Using crowbar (2-metre bar) to lever open vehicle doors/bonnet

Code 112: Rescue trapped people, animals

- Moving people (often obese) using canvas/salvage sheets
- Rescue firefighter/victim while wearing PPE and BA
- Rescue via ladder
- Rescue via stairs
- Prolonged crawling, kneeling, crouching, squatting, dragging: rescue
- Prolonged static work (*e.g.* holding victim's head)
- Moving victims with Stokes Litter (cliff rescue)

Code 113: Assist to rescue people, animals (confined spaces)

- Moving people (often obese) using canvas/salvage sheets
- Rescue via ladder
- Rescue via stairs
- Prolonged crawling, kneeling, crouching, squatting, dragging: rescue
- Ladder use: removal, replacement, under running
- Ladder stabilisation: usually 2-3 people, sometimes 1 person
- Prolonged static work (*e.g.* holding victim's head)
- Moving victims with Stokes Litter (cliff rescue)

APPENDIX THREE

Table: Characteristics of the items (external loads) used within the fire-fighting simulations. Quantity refers to the average number of items on a typical appliance (truck).

Simulation	Equipment Items	Size	Mass	Quantity
Hazmat	Bin, hazmat recovery	960 mm * 710 mm * 710 mm	28 kg (200 L)	1
Motor-vehicle rescue	Block step (6 piece)	600 mm * 100 mm * 75 mm	7.2 kg	1
All simulations except motor-vehicle rescue	Breathing apparatus, self-contained, air set	530 mm * 140 mm * 140 mm	11.6 kg	6
Motor-vehicle rescue, stair climb with fully charged 38-mm hose	Crowbar	1800 mm * 25 mm	5.8 kg	1
Stair climb with fully charged 38-mm hose	Halligan Tool	750 mm * 175 mm * 170 mm	4.5 kg	1
Locating and connecting a hydrant	Hose assembly set, hydraulic	5 and 10 m	5 m= 4.9 kg 10 m= 6.9 kg	3
Locating and connecting a hydrant	Hydrant, fire, bar	600 mm	1.8 kg	1
Locating and connecting a hydrant	Hydrant, fire, delivery elbow	540 mm * 120 mm * 100 mm	7.1 kg	1
Locating and connecting a hydrant	Hydrant, fire, standpipe, single head	190 mm * 300 mm * 930 mm	8 kg	2
Coupling and uncoupling hoses	Hydrant, fire, wide breach	70 mm	5 kg	1

Simulation	Equipment Items	Size	Mass	Quantity
Use of the 10.5-m ladder	Ladder, fire, extension	10.7 m (extendable)	49.6 kg	1
Motor-vehicle rescue	Shear set, hydraulic, double acting	830 mm * 220 mm * 125 mm	13 kg	1
Motor-vehicle rescue	Spreaders, double acting	920 mm * 810 mm * 300 mm	19.5 kg	1
Motor-vehicle rescue	Sheet, non-metallic, protective, salvage	3600 mm * 3600 mm	8.3 kg	2
Use of sledge axe to gain entry	Sledge axe	750-mm long	4.7 kg	1
Hazmat	Suit kit, chemical protective	Height: 2.2 m Armspan: 2.0 m	7.7 kg	2
Stair climb with ventilation fan	Ventilation fan	560 mm * 500 mm * 400 mm	35 kg	1
Hot-fire cell rescue	Viewer set, thermal imaging	275 mm * 112 mm * 205 mm	1.35 kg	1
Hot-fire cell rescue, stair climb with fully charged 38-mm hose, bush drag, fire attack, firefighter rescue, prolonged use of 38-mm hose	38-mm hose, charged	30 m	~35 kg	10
Drag charged 70-mm hose laterally, prolonged use of 70-mm hose	70 mm hose, charged	30 m	~115 kg	10

Simulation	Equipment Items	Size	Mass	Quantity
Locating and connecting a hydrant, rolling out hoses (70 mm), coupling hoses	70-mm hose, rolled	$520 mm^2$ * 100 mm	16.6 kg	10

Note: The mass of the hoses is indicative of an entire length (30 m) of hose. The mass held in the firefighters hands in an isometric position (*e.g.* the prolonged use of the 38-mm hose) would have been much less than this mass (*e.g.* 7-8 kg).

APPENDIX FOUR

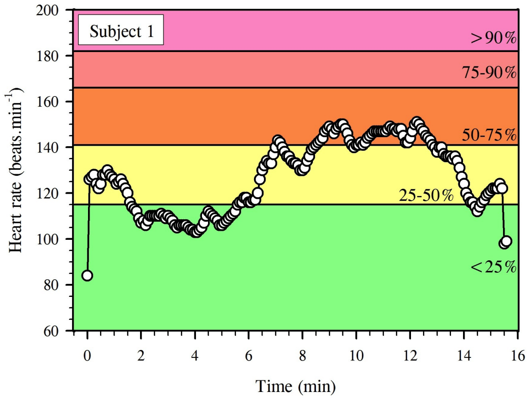

Figure A4.1: Heart rate response of one firefighter during the motor-vehicle rescue simulation.

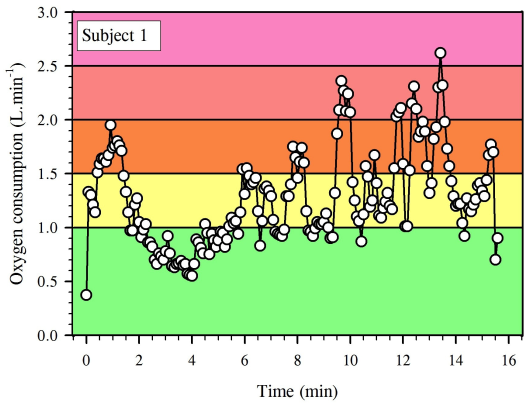

Figure A4.2: Oxygen consumption response of one firefighter during the motor-vehicle rescue simulation.

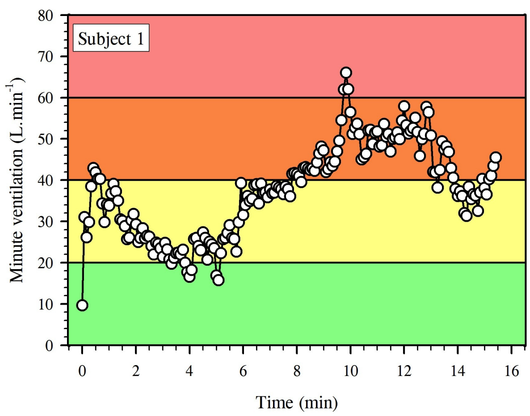

Figure A4.3: The ventilatory response of one firefighter during the motor-vehicle rescue simulation.

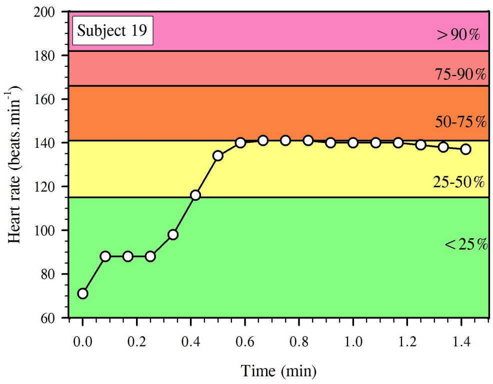

Figure A4.4: Heart rate response of one firefighter performing a hose roll-out (bowling 70 mm) simulation.

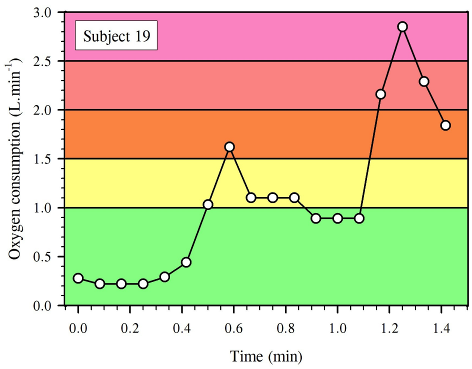

Figure A4.5: Oxygen consumption response of one firefighter performing a hose roll-out (bowling 70 mm) simulation.

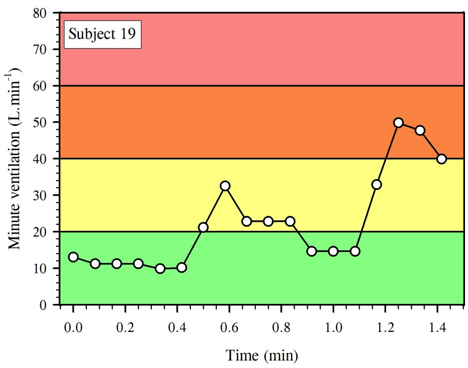

Figure A4.6: The ventilatory response of one firefighter performing a hose roll-out (bowling 70 mm) simulation.

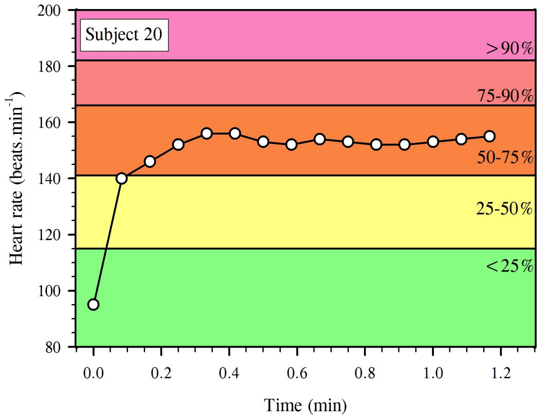

Figure A4.7: Heart rate response of one firefighter during the hose-coupling simulation.

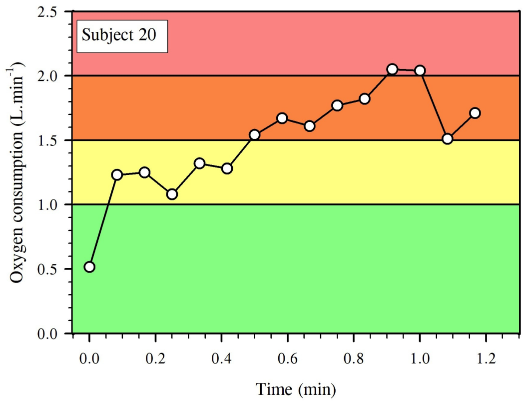

Figure A4.8: Oxygen consumption response of one firefighter during the hose-coupling simulation.

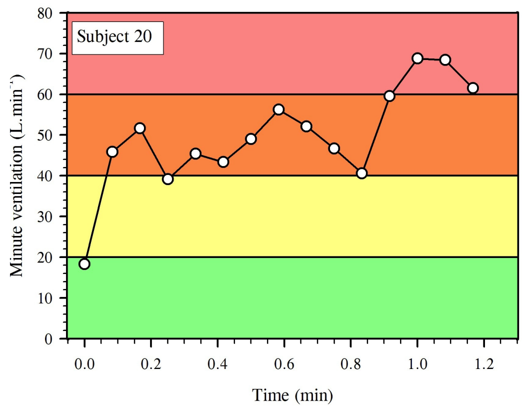

Figure A4.9: The ventilatory response during the hose-coupling simulation.

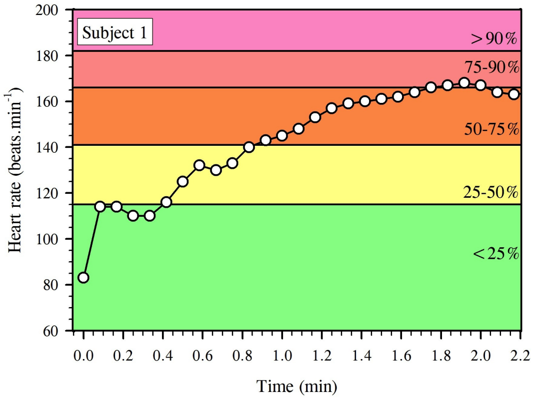

Figure A4.10: Heart rate response of one firefighter during the fire-hydrant connection simulation.

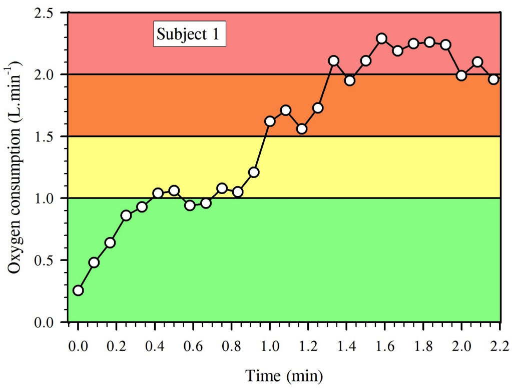

Figure A4.11: Oxygen consumption response of one firefighter during the fire-hydrant connection simulation.

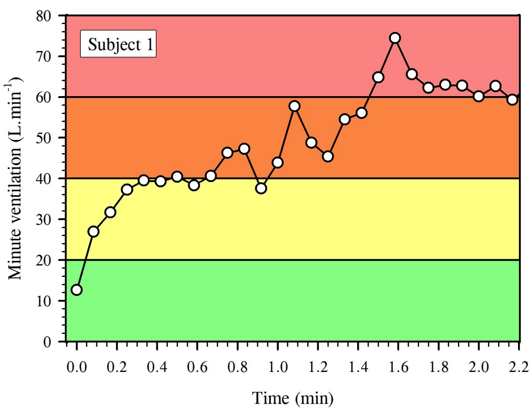

Figure A4.12: The ventilatory response during the fire-hydrant simulation.

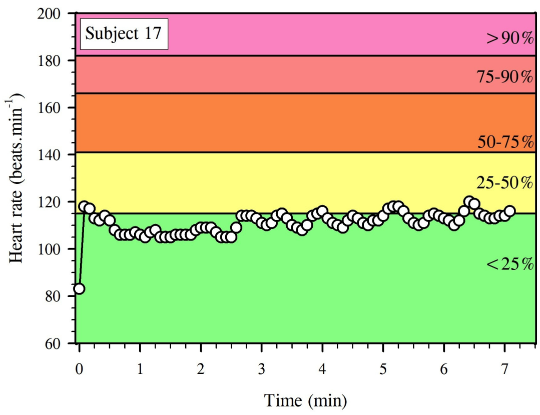

Figure A4.13: Heart rate response of one firefighter during the lateral movement of a charged 70-mm hose.

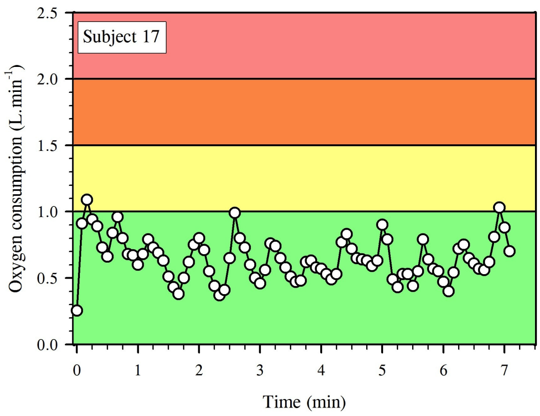

Figure A4.14: Oxygen consumption response of one firefighter during the lateral movement of a charged 70-mm hose.

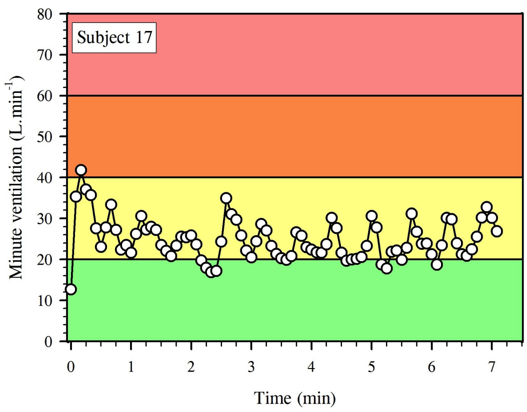

Figure A4.15: The ventilatory response of one firefighter during the lateral movement of a charged 70-mm hose.

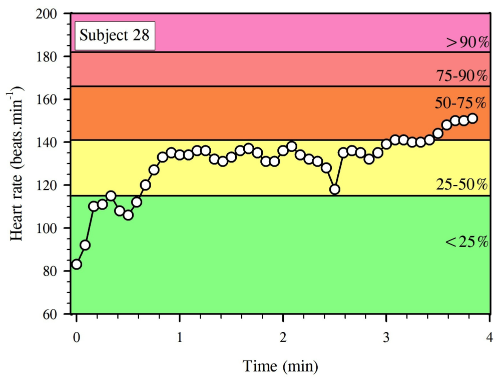

Figure A4.16: Heart rate response of one firefighter during the fire-attack simulation.

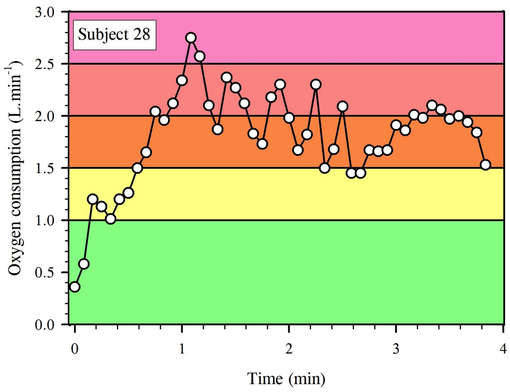

Figure A4.17: Oxygen consumption response of one firefighter during the fire-attack simulation.

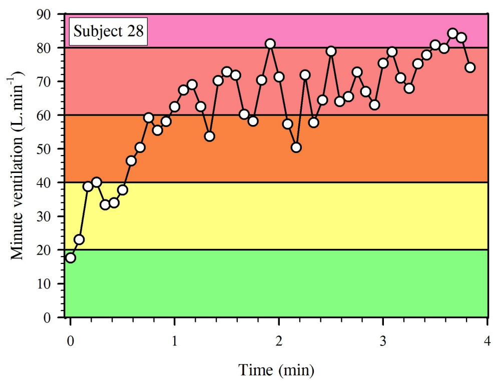

Figure A4.18: The ventilatory response of one firefighter during the fire-attack simulation.

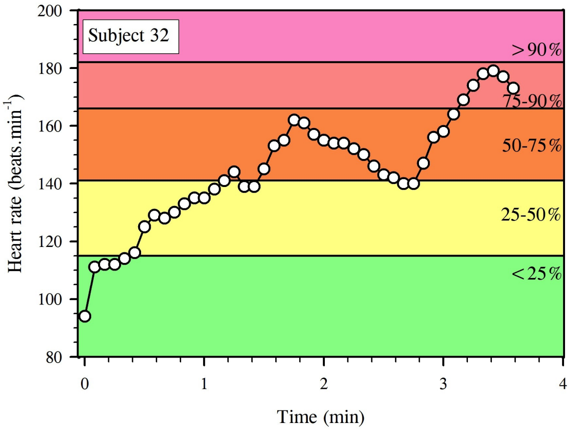

Figure A4.19: Heart rate response of one firefighter during the one-person firefighter rescue simulation.

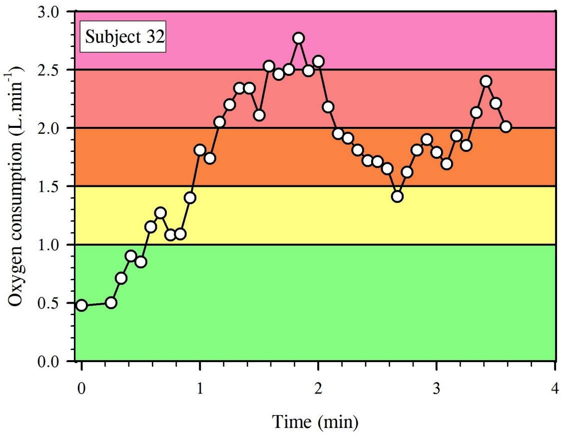

Figure A4.20: Oxygen consumption response of one firefighter during the one-person firefighter rescue simulation.

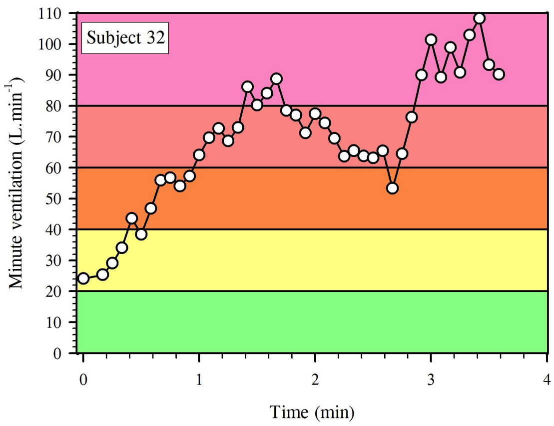

Figure A4.21: The ventilatory response of one firefighter during the firefighter rescue simulation.

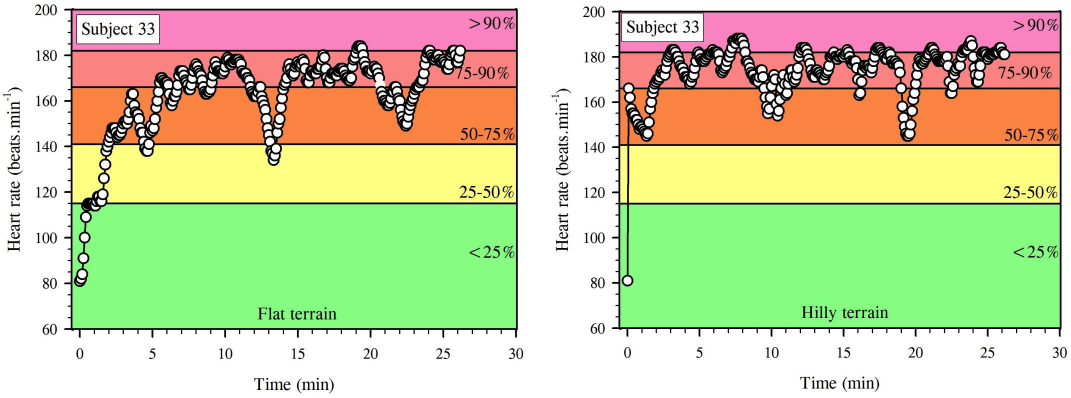

Figure A4.22: Heart rate response of one firefighter during the bushfire (hose-drag) simulation: flat (left) and hilly terrain.

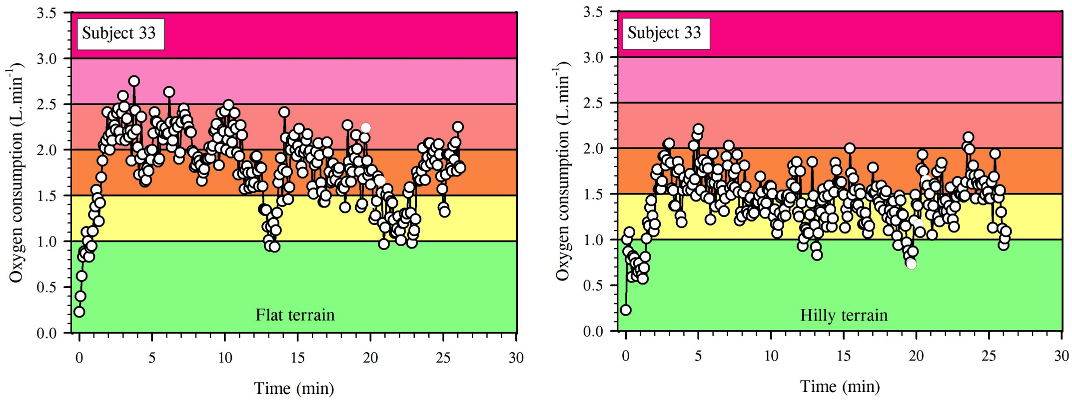

Figure A4.23: Oxygen consumption response of one firefighter during the bushfire (hose-drag) simulation: flat (left) and hilly terrain.

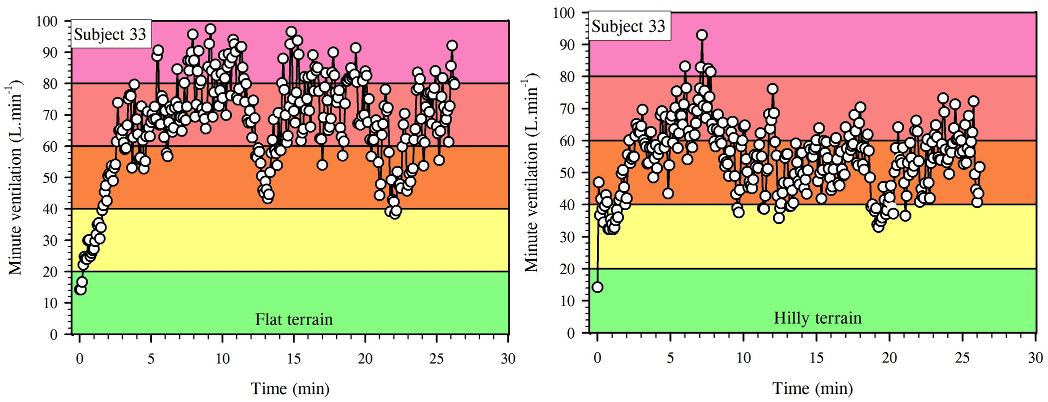

Figure A4.24: The ventilatory response of one firefighter during the bushfire (hose-drag) simulation: flat (left) and hilly terrain.

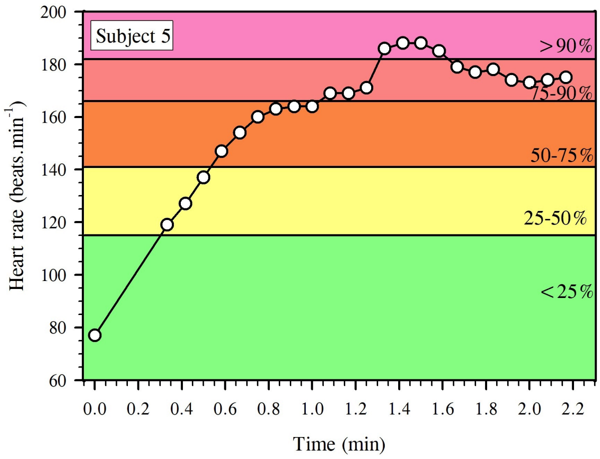

Figure A4.25: Heart rate response of one firefighter during the stair-climb simulation dragging a charge 38-mm hose (leading firefighter).

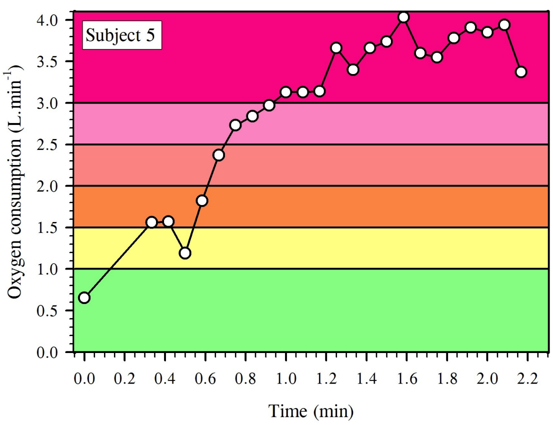

Figure A4.26: Oxygen consumption response of one firefighter during the stair-climb simulation dragging a charge 38-mm hose (leading firefighter).

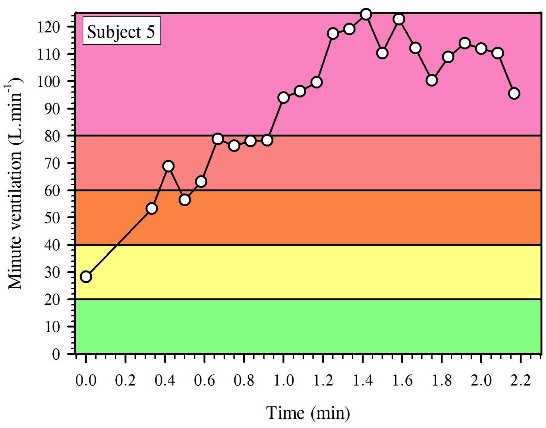

Figure A4.27: The ventilatory response of one firefighter during the stair-climb simulation dragging a charge 38-mm hose (leading firefighter).

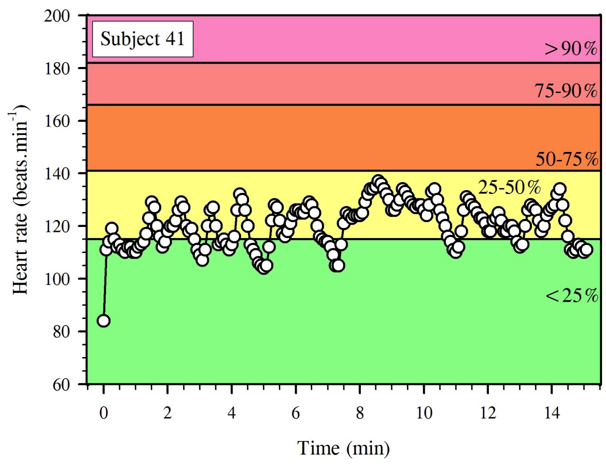

Figure A4.28: Heart rate response of one firefighter during the prolonged use of a 38-mm hose.

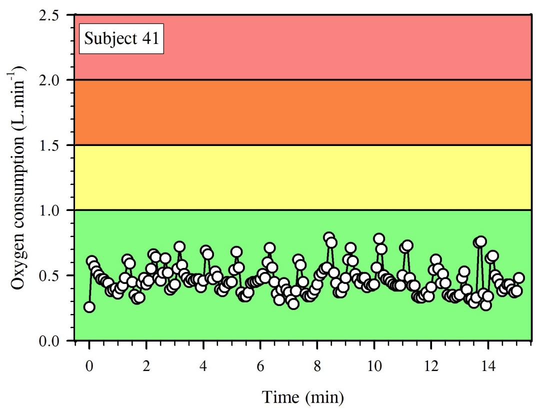

Figure A4.29: Oxygen consumption response of one firefighter during the prolonged use of a 38-mm hose.

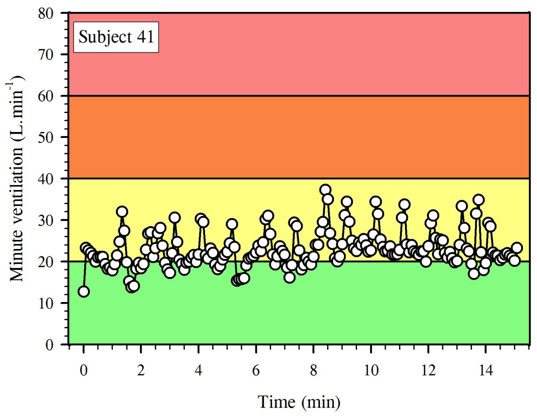

Figure A4.30: The ventilatory response of one firefighter during the prolonged use of a 38-mm hose.

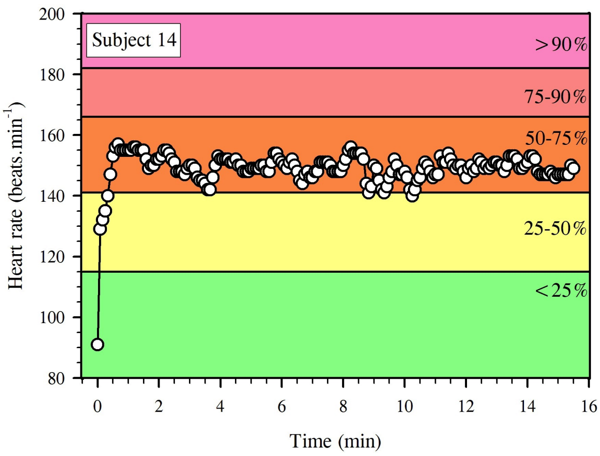

Figure A4.31: Heart rate response of one firefighter during the prolonged use of a 70-mm hose.

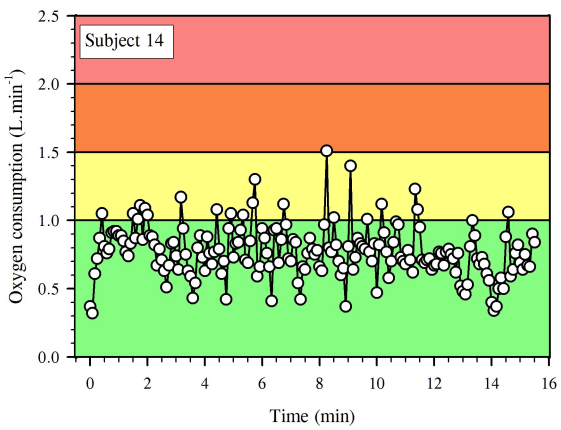

Figure A4.32: Oxygen consumption response of one firefighter during the prolonged use of a 70-mm hose.

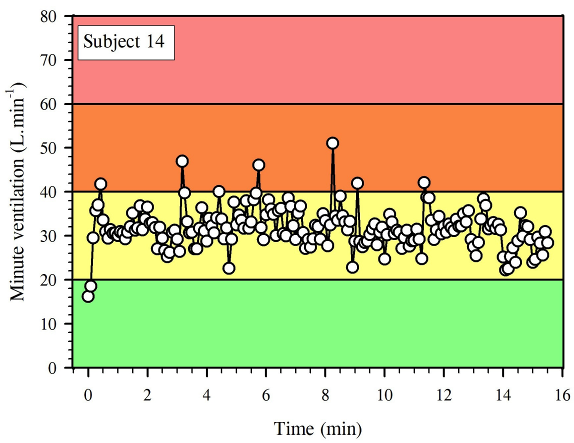

Figure A4.33: The ventilatory response of one firefighter during the prolonged use of a 70-mm hose.

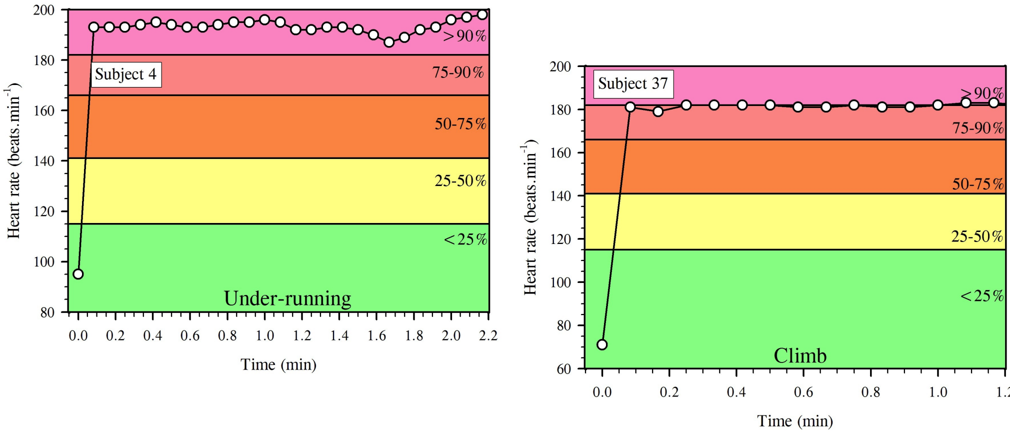

Figure A4.34: Heart rate response of two firefighters during two ladder-use simulations: under-running (left) and a ladder ascent.

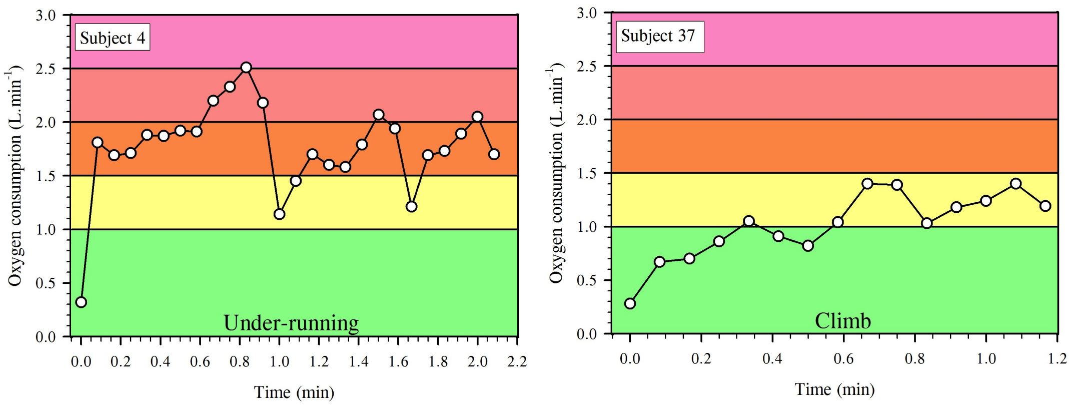

Figure A4.35: Oxygen consumption response of two firefighters during two ladder-use simulations: under-running (left) and a ladder ascent.

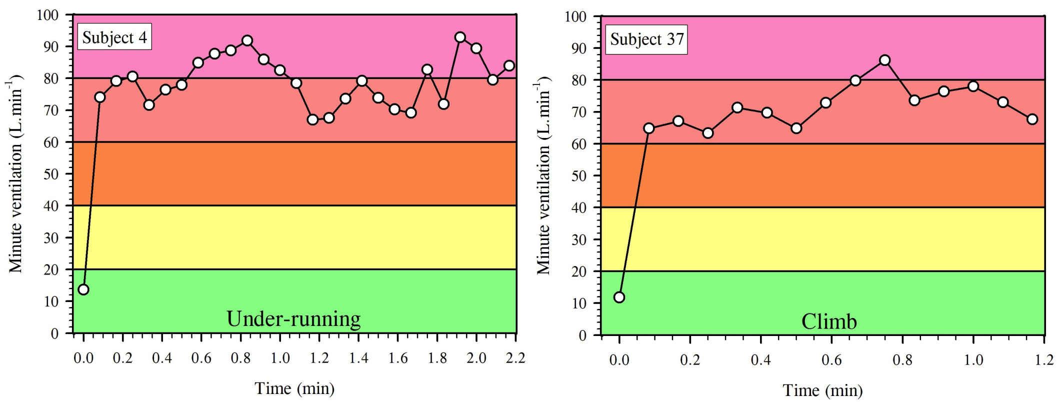

Figure A4.36: The ventilatory response of two firefighters during two ladder-use simulations: under-running (left) and a ladder ascent.

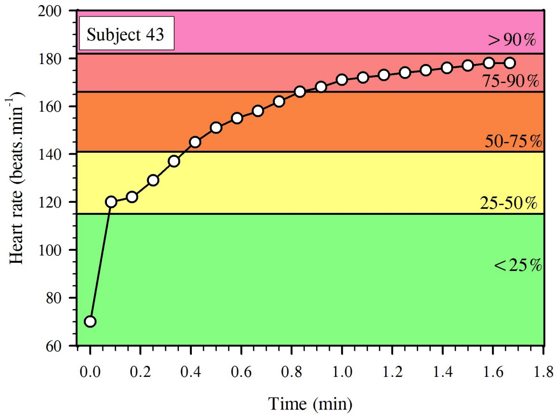

Figure A4.37: Heart rate response of one firefighter during the ventilation fan carry simulation (up stairs).

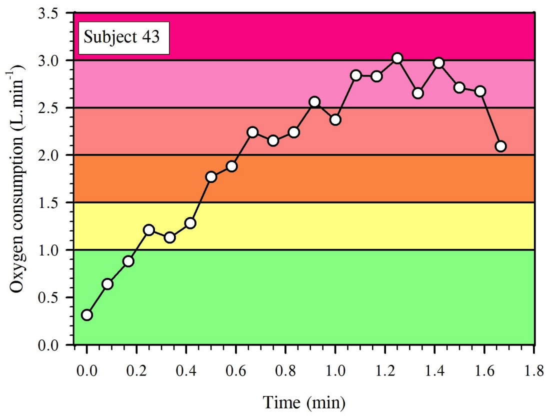

Figure A4.38: Oxygen consumption response of one firefighter during the ventilation fan carry simulation (up stairs).

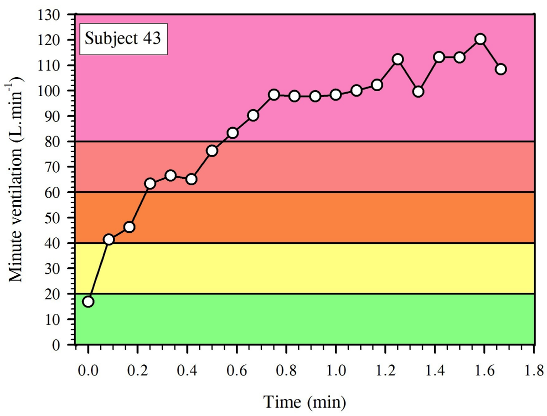

Figure A4.39: The ventilatory response of one firefighter during the ventilation fan carry simulation (up stairs).

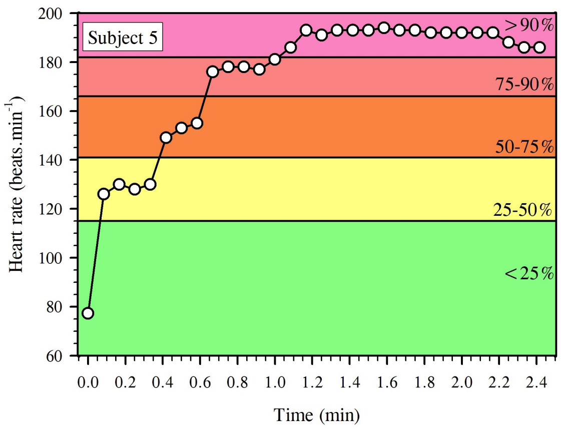

Figure A4.40: Heart rate response of one firefighter during the sledge axe door entry simulation.

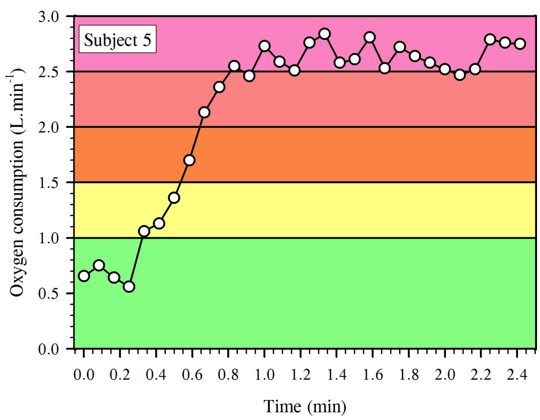

Figure A4.41: Oxygen consumption response of one firefighter during the sledge axe door entry simulation.

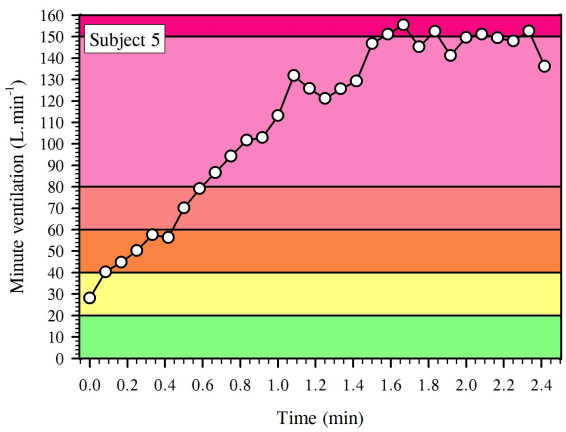

Figure A4.42: The ventilatory response of one firefighter during the sledge axe door entry simulation.

APPENDIX FIVE:

Meeting to discuss possible physiological screening test options for the approved criterion trade tasks arising from work done in Chapters Two and Three of this dissertation.

Date: 21/05/12
Location: Deans Meeting Room (University of Wollongong).
Present: Brendan Mott (FRNSW), Hugh Fullagar (Author - UOW), Nigel Taylor (Research Team - UOW), Herb Groeller (Research Team - UOW), John Sampson (Research Team - UOW).

Summary:
The first purpose of this meeting was to present and evaluate a preliminary proposal for the classification of the criterion tasks. Since there were movement pattern similarities across these tasks, then each criterion task was classified into one of four different movement categories. This was driven primarily by HF and HG, following input from NT and JS.

During these discussions, it was proposed by the author (following confirmation from the Research Team) to sub-divide the ladder task into two parts (carrying and under-running) as it was considered to fall within each of two different movement classes. The second aim of this meeting was to identify operational constraints that may subsequently influence test selection, design and implementation. This process was largely driven by BM with scientific input from the author and the Research Team. Finally, criteria were discussed upon which individual tasks may be eliminated from the list, since it was considered that some duplication may exist among these criterion tasks, and task culling would increase testing efficiency.

Six constraints of practical or logistical significance were identified and discussed in detail:

- environmental constraints: locations and facilities for test administration, and climatic variations
- equipment constraints: personal protective clothing and equipment
- the height of the operating posture (below the neutral plane) for firefighters to avoid excessive heat and smoke exposure
- the structures and surfaces used during ambulatory and load-carriage tasks
- the mass that would be used within the crucial strength task (patient mass)
- the correlation of a "lift and place" activity with critical tasks that require the holding of variously sized objects.

Each was carefully considered when determining the suitability of any criterion task, or a modification thereof, for inclusion within an occupation-specific physiological screening test.

Three exclusion criteria were identified:

- a low relative, whole-body physiological demand
- movement task duplication
- the availability of suitable substitution tasks.

Should any task satisfy one or more of these characteristics, it would be considered for elimination by the author and the Research Team. In this way, efficiencies within the proposed fire-fighter physical aptitude test could be found, without compromising either the sensitivity or specificity of the proposed physiological screening test.